dsPICDEM™ MC1H 3-Phase High Voltage Power Module User's Guide

© 2003 Microchip Technology Inc.

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as “unbreakable.”

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break microchip’s code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

Information contained in this publication regarding device applications and the like is intended through suggestion only and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications. No representation or warranty is given and no liability is assumed by Microchip Technology Incorporated with respect to the accuracy or use of such information, or infringement of patents or other intellectual property rights arising from such use or otherwise. Use of Microchip’s products as critical components in life support systems is not authorized except with express written approval by Microchip. No licenses are conveyed, implicitly or otherwise, under any intellectual property rights.

Trademarks

The Microchip name and logo, the Microchip logo, dsPIC, KEELOQ, MPLAB, PIC, PICmicro, PICSTART, PRO MATE and PowerSmart are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

FilterLab, microID, MXDEV, MXLAB, PICMASTER, SEEVAL and The Embedded Control Solutions Company are registered trademarks of Microchip Technology Incorporated in the U.S.A.

Accuron, Application Maestro, dsPICDEM, dsPICDEM.net, ECONOMONITOR, FanSense, FlexROM, fuzzyLAB, In-Circuit Serial Programming, ICSP, ICEPIC, microPort, Migratable Memory, MPASM, MPLIB, MPLINK, MPSIM, PICC, PICkit, PICDEM, PICDEM.net, PowerCal, PowerInfo, PowerMate, PowerTool, rfLAB, rfPIC, Select Mode, SmartSensor, SmartShunt, SmartTel and Total Endurance are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

Serialized Quick Turn Programming (SQTP) is a service mark of Microchip Technology Incorporated in the U.S.A.

All other trademarks mentioned herein are property of their respective companies.

© 2003, Microchip Technology Incorporated, Printed in the U.S.A., All Rights Reserved.

Printed on recycled paper.

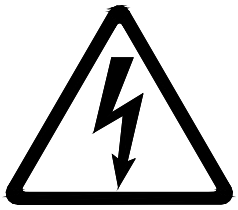
DNV Certification, Inc. USA — ANSI-RAB QMS ACCREDITED — DNV MSC The Netherlands Accredited by the RvA — DNV — ISO 9001 / QS-9000 REGISTERED FIRM

Microchip received QS-9000 quality system certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona in July 1999 and Mountain View, California in March 2002. The Company’s quality system processes and procedures are QS-9000 compliant for its PICmicro® 8-bit MCUs, KEELOQ® code hopping devices, Serial EEPROMs, microperipherals, non-volatile memory and analog products. In addition, Microchip’s quality system for the design and manufacture of development systems is ISO 9001 certified.

© 2003 Microchip Technology Inc.

Safety Notice

The safety notices and operating instructions provided should be adhered to, to avoid a safety hazard. If in any doubt, consult your supplier.



WARNING – This system must be earthed (grounded) at all times.

CAUTION – The system should not be installed, operated, serviced or modified except by qualified personnel who understand the danger of electric shock hazards and have read and understood the user instructions. Any service or modification performed by the user is done at the user's own risk and voids all warranties.

WARNING – The output terminals are NOT isolated from the incoming AC mains supply and may be at up to 410V with respect to ground, regardless of the input mains supply voltage applied. These terminals are live during operation AND for 3 minutes after disconnection from the supply. Do not attempt to access the terminals or remove the cover during this time. Note that this same shock hazard applies to any external brake resistor connected, which will also be live, and therefore protection equivalent to double insulation should be provided.

WARNING – The unit may obtain power through the output terminals if these are connected to a rotating motor acting as a generator. If this is the case, then the previous warning also applies (i.e., the output terminals are live when connected to the generator and for 3 minutes after the generator has been stopped). Note that this case can arise even when the unit has been disconnected from the incoming AC mains supply.

CAUTION – If a motor is connected to the output of this unit, the frame should be connected to the output protective ground terminal provided. Particular care should be taken to mechanically guard such a motor, bearing in mind that unexpected behavior is likely to result from the process of code development.

CAUTION – For continued protection against the risk of fire, replace the fuse with one of the same type only (i.e., T5A H 250V, Time Lag 5A High Breaking Capacity 250V minimum).

© 2003 Microchip Technology Inc.

- **The system is intended for evaluation and development purposes and should only be operated in a normal laboratory environment as defined by IEC 61010-1:2001.**
- **Clean with a dry cloth only.**
- **Operate flat on a bench, do not move during operation and do not block the ventilation holes.**
- **The system should not be operated without all the supplied covers fully secured in place.**
- **Screws should not protrude into the unit by more than 5 mm (0.2″), type M3 ISO metric.**
- **The system should not be connected or operated if there is any apparent damage to the unit.**
- **The unit is designed for installation category II and to be connected to the AC mains supply via a standard non-locking plug. As the unit has no mains switch, this plug constitutes the means of disconnection from the supply and thus the user must have unobstructed access to this plug during operation.**

© 2003 Microchip Technology Inc.

Table of Contents

Safety Notice ..... **iii**

Preface **1**

Chapter 1. Set Up and Operation

1.1 Introduction 5

1.2 Using The Motor Control 3-Phase High Power Module 7

1.3 Current and Power Limitations 14

1.4 Detailed Description of Operation 17

1.5 Modifying The Board 30

1.6 Test Points 36

1.7 User Signal Connector Pinout (37-Pin, D-Type) 37

Appendix A: Circuit Diagrams **39**

Appendix B: Source Code **47**

Worldwide Sales and Service **54**

© 2003 Microchip Technology Inc.

NOTES:

© 2003 Microchip Technology Inc.

Preface

This chapter contains general information about this manual and contacting customer support.

HIGHLIGHTS

Topics covered in this chapter:

- About this Guide
- Warranty Registration
- Recommended Reading
- The Microchip Web Site
- Development Systems Customer Notification Service
- Customer Support

ABOUT THIS GUIDE

Document Layout

This document describes how to use the Microchip dsPICDEM™ MC1H High Voltage 3-Phase Power Module. The manual layout is as follows:

- **Chapter 1: Set Up and Operation** – Describes what the product is, what makes it a desirable development tool, how to install it and the basic features of the interface.
- **Worldwide Sales and Service** – Lists Microchip sales and service locations and telephone numbers worldwide.

Documentation Updates

All documentation becomes dated and this user's guide is no exception. Since MPLAB® IDE, MPLAB C1X and other Microchip tools are constantly evolving to meet customer needs, some actual dialogs and/or tool descriptions may differ from those in this document. Please refer to our web site to obtain the latest documentation available.

Documentation Numbering Conventions

Documents are numbered with a "DS" number. The number is located on the bottom of each page, in front of the page number. The numbering convention for the DS Number is: DSXXXXXA,

where:

XXXXX	=	The document number.
A	=	The revision level of the document.

© 2003 Microchip Technology Inc.

dsPICDEM™ MC1H 3-Phase High Voltage Power Module

WARRANTY REGISTRATION

Please complete the enclosed Warranty Registration Card and mail it promptly. Sending in your Warranty Registration Card entitles you to receive new product updates. Interim software releases are available at the Microchip web site.

RECOMMENDED READING

This user's guide describes how to use the dsPICDEM MC1H 3-Phase High Voltage Power Module. The data sheets contain current information on programming the specific microcontroller devices.

THE MICROCHIP WEB SITE

Microchip provides online support on the Microchip World Wide Web (WWW) site. The web site is used by Microchip as a means to make files and information easily available to customers. To view the site, you must have access to the Internet and a web browser such as Netscape Navigator® or Microsoft® Internet Explorer.

The Microchip web site is available by using your favorite Internet browser to attach to:

http://www.microchip.com

The web site provides a variety of services. Users may download files for the latest development tools, data sheets, application notes, user's guides, articles and sample programs. A variety of information specific to the business of Microchip is also available, including listings of Microchip sales offices, distributors and factory representatives.

Technical Support

- Frequently Asked Questions (FAQ)
- Online Discussion Groups - Conferences for products, Development Systems, technical information and more
- Microchip Consultant Program Member Listing
- Links to other useful web sites related to Microchip products

Engineer's Toolbox

- Design Tips
- Device Errata

Other available information

- Latest Microchip Press Releases
- Listing of seminars and events
- Job Postings

© 2003 Microchip Technology Inc.

DEVELOPMENT SYSTEMS CUSTOMER NOTIFICATION SERVICE

Microchip started the customer notification service to help our customers keep current on Microchip products with the least amount of effort. Once you subscribe, you will receive e-mail notification whenever we change, update, revise or have errata related to your specified product family or development tool.

Go to the Microchip web site at (http://www.microchip.com) and click on Customer Change Notification. Follow the instructions to register.

The Development Systems product group categories are:

- Compilers
- Emulators
- In-Circuit Debuggers
- MPLAB® Development Systems
- Programmers

Here is a description of these categories:

Compilers – The latest information on Microchip C compilers and other language tools. These include the MPLAB C17, MPLAB C18 and MPLAB C30 C compilers; MPASM™ and MPLAB ASM30 assemblers; MPLINK™ and MPLAB LINK30 object linkers; MPLIB™ and MPLAB LIB30 object librarians.

Emulators – The latest information on Microchip in-circuit emulators. This includes the MPLAB® ICE 2000 and MPLAB® ICE 4000.

In-Circuit Debuggers – The latest information on Microchip in-circuit debuggers. These include the MPLAB® ICD and MPLAB ICD 2.

MPLAB Development Systems – The latest information on Microchip MPLAB® IDE, the Windows® Integrated Development Environment for development systems tools. This list is focused on the MPLAB® IDE, MPLAB SIM and MPLAB SIM30 simulators, MPLAB IDE Project
Manager and general editing and debugging features.

Programmers – The latest information on Microchip device programmers. These include the PRO MATE® II device programmer and PICSTART® Plus development programmer.

© 2003 Microchip Technology Inc.

CUSTOMER SUPPORT

Users of Microchip products can receive assistance through several channels:

- Distributor or Representative
- Local Sales Office
- Field Application Engineer (FAE)
- Corporate Applications Engineer (CAE)
- Hotline

Customers should call their distributor, representative or field application engineer (FAE) for support. Local sales offices are also available to help customers. See the back cover for a list of sales offices and locations.

Corporate Applications Engineers (CAEs) may be contacted at (480) 792-7627.

In addition, there is a Systems Information and Upgrade Line. This line provides system users a list of the latest versions of all of Microchip's development systems software products. Plus, this line provides information on how customers can receive any currently available upgrade kits.

The Hotline Numbers are:

1-800-755-2345 for U.S. and most of Canada.

1-480-792-7302 for the rest of the world.

© 2003 Microchip Technology Inc.

Chapter 1. Set Up and Operation

1.1 INTRODUCTION

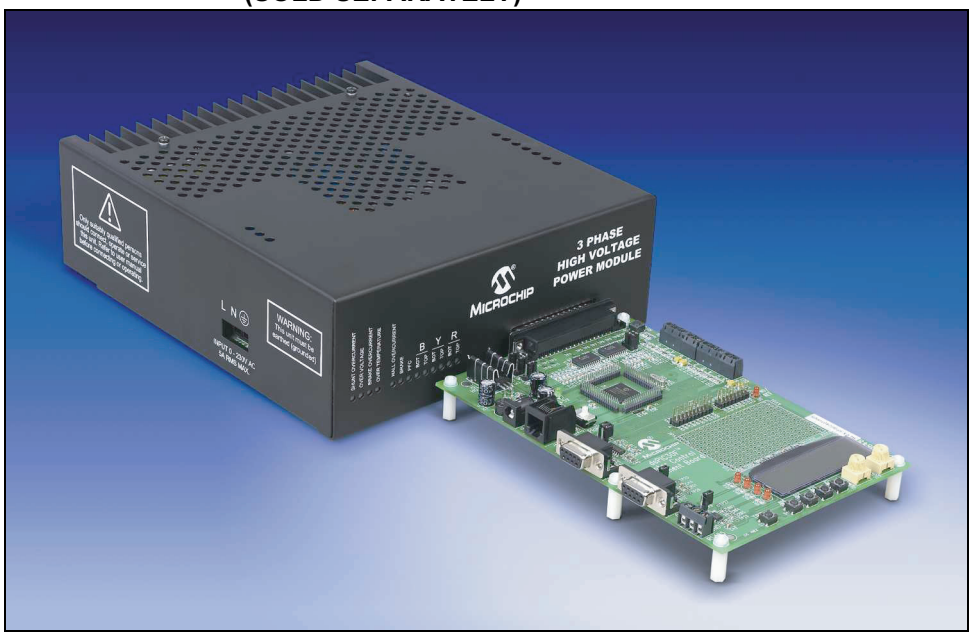
The Microchip dsPICDEM MC1H 3-Phase High Voltage Power Module is intended to aid the user in the rapid evaluation and development of a wide variety of motor control applications using the dsPIC® microcontroller. The design of the system includes Microchip analog components, as well as a PIC® microcontroller used to provide isolated voltage feedback. The main components of the system are shown in Figure 1-2.

The rated continuous output current from the inverter is 2.5A (RMS). This allows up to approximately 0.8 kVA output when running from a 208V to 230V single-phase input voltage in a maximum 30°C (85F) ambient temperature environment. Thus, the system is ideally suited to running a standard 3-Phase Induction Motor of up to 0.55 kW (0.75 HP) rating or an industrial servomotor of slightly higher rating. The power module is capable of driving other types of motors and electrical loads that do not exceed the maximum power limit and are predominantly inductive. Furthermore, single-phase loads can be driven using 1 or 2 of the inverter outputs.

The unit is capable of operating from any AC voltage up to a maximum of 265V. Operation at voltages beneath 208V requires that the output power is reduced owing to inverter output and AC input stage current limits. A more detailed explanation of power limitations is given in **Section 1.4 "Detailed Description of Operation"**.

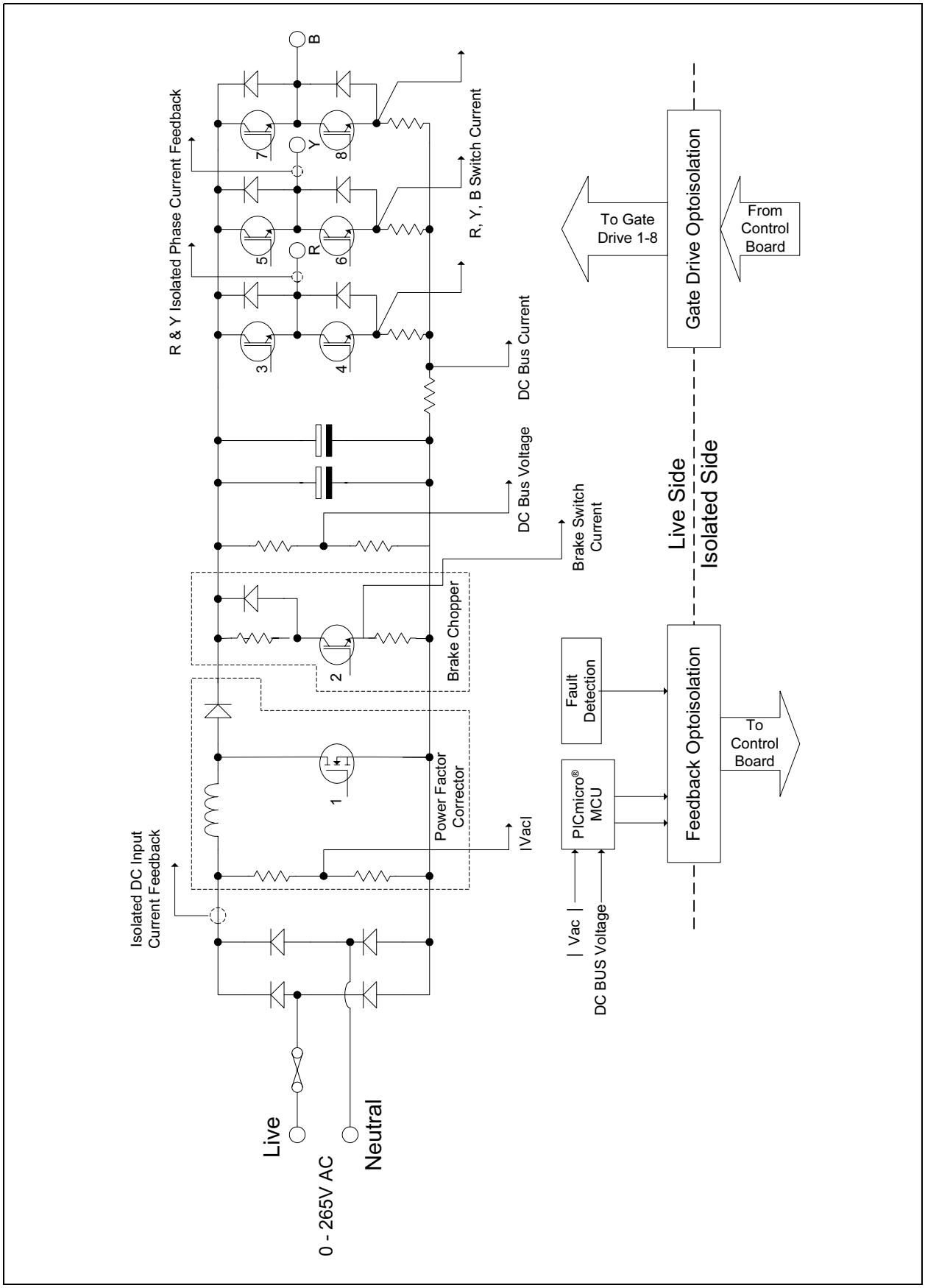
The user should read **Section 1.3 "Current and Power Limitations"** and **Section 1.4 "Detailed Description of Operation"** carefully before using the system.

FIGURE 1-1: POWER MODULE WITH ATTACHED DEVELOPMENT BOARD (SOLD SEPARATELY)



© 2003 Microchip Technology Inc.

FIGURE 1-2: MC1H 3-PHASE HIGH VOLTAGE POWER MODULE BLOCK DIAGRAM



© 2003 Microchip Technology Inc.

1.2 USING THE MOTOR CONTROL 3-PHASE HIGH POWER MODULE

1.2.1 Introduction

The user should be aware of the operating procedures outlined below and ensure that they are followed. Failure to do so may result in damage to the system.

1.2.2 Making Power Connections

It is recommended that cables be terminated with blue or red insulated crimp terminals. If crimp terminals are not used, care should be taken to ensure that stray strands of wire do not short to adjacent terminals or the enclosure. If possible, all wires should be stripped and tinned with solder before connecting to the power module terminals.

For the AC mains supply input, standard double-insulated, 3-core flex cable should be used with a minimum current rating of 10A (1 mm^2 18 AWG). A computer power cable can be used when the IEC connector is removed.

Note: The system is designed for installation category II. Therefore, the incoming mains cable should be wired into a standard non-locking 2-pin + ground type plug.

The recommended output cable size is 1.0 to 1.5 mm^2 (18-16 AWG) and it should have a 600V rating. This cable should also be double insulated or have a protective ground screen.

Access to the terminal screws is provided via holes in the lid of the enclosure. A flat blade screwdriver should be used.

Note: The user should only access the power terminals when the system is fully discharged (see Safety Notice).

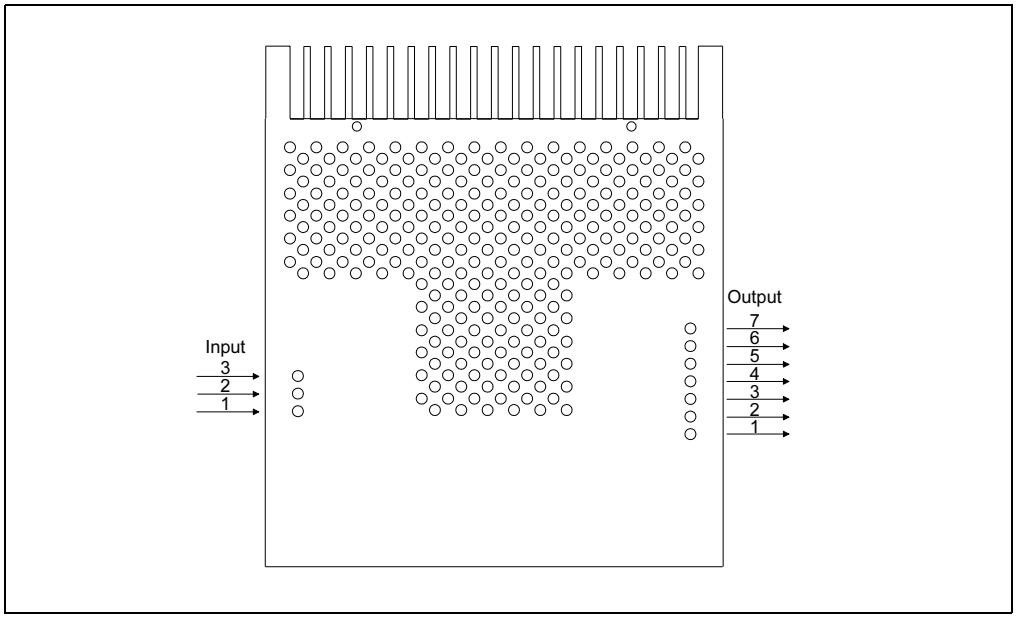
The power connections are shown in Table 1-1 and Figure 1-3:

TABLE 1-1: POWER CONNECTIONS

Connection Number	Input	Output
1	Ground	Ground
2	Neutral	Red Phase
3	Live (Fused)	Yellow Phase
4	—	Blue Phase
5	—	-DC Bus
6	—	External Brake Resistor
7	—	+DC Bus

© 2003 Microchip Technology Inc.

FIGURE 1-3: POWER CONNECTIONS



Using output connections 6 and 7, the user may connect an external braking resistor. The user should consider the maximum and average power to be dissipated at the required DC bus voltage when considering the resistor value. They should also consider the peak allowable resistor current of 4A. For example, if regulating at 400V then a 100Ω minimum value should be used which would allow 1.6 kW (at most) to be dissipated.

The user may feed in an external DC supply using output connections 5 and 7. This offers the simplest way for a user to bypass the PFC section of the unit. In the simplest case all the user needs to do is use an external rectifier and fuse. The input current rating when using the auxiliary DC input is 15A (RMS). The inverter output rating is unchanged. Note that if using the auxiliary DC input, the internal fuse, soft-start, PFC and ground FAULT protection is bypassed. It is up to the user to ensure adequate external protection circuitry is used and incoming DC voltage is correctly regulated.

1.2.3 Connecting To The Control Board

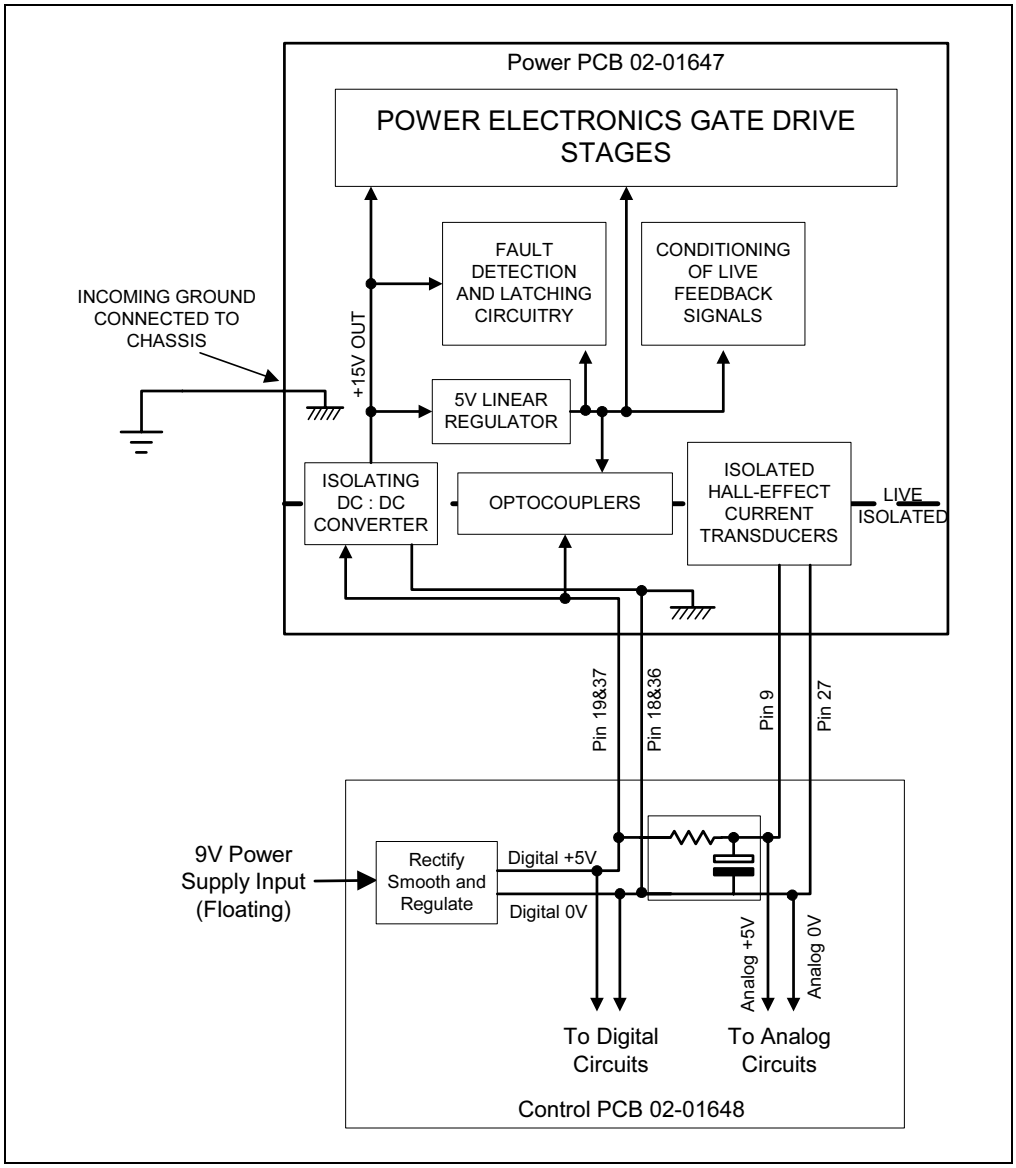
The system has been designed so that the Microchip dsPICDEM MC1 Motor Control Development Board (02-01648) plugs directly into the 37-pin, D-Type connector. **Section 1.7 "User Signal Connector Pinout (37-Pin, D-Type)"** contains details of the pin allocation.

Correct operation with the use of an extension cable can not be guaranteed as it may introduce additional noise. If an extension is used, it should be as short as possible and use screened cable.

The power module derives its low voltage power supplies from the control PCB. The supplies on the isolated supply are taken directly from the control PCB via the 37-pin connector. The supplies on the live side of the isolation barrier are derived using an isolating DC-DC converter that is connected to the digital +5V supply input on the 37-pin connector. In this way, the power module may be used at any input voltage up to the maximum. This arrangement is shown in Figure 1-4.

© 2003 Microchip Technology Inc.

FIGURE 1-4: POWER ELECTRONICS GATE DRIVE STAGES



Note that the incoming digital 0V from the development board is grounded within the power module (as shown in Figure 1-4) to ensure user safety. When a PC or any other device is connected to the control board there is therefore the possibility of a “ground loop” occurring. If this is suspected, the user should first try to eliminate the stray magnetic field causing the problem by relocating the offending transformer or by using shielding. If this is not possible, then the equipment connected to the development board should be isolated from the digital 0V.

Position and speed feedback transducers are connected to the control board directly and not via the power module. No electrical isolation is provided on the control board for these signals and so the transducers must be isolated.

Consult the development board documentation for details of signal interfacing and how to connect in-circuit emulators and debugging equipment.

1.2.4 Power-Up/Power-Down Sequence

The user should ensure that the following sequence are followed.

1.2.4.1 POWER-UP SEQUENCE

- With the development board plugged in, turn on the power supply feeding the control PCB (if not already on).
- One or more of the fault lights may illuminate. This is normal.
- Turn on the AC supply to the power module.
- Reset the system by activating the active high ISO_RESET line. The ISO_RESET line is on pin 33 of the 37-pin, D-type (see **Section 1.7 "User Signal Connector Pinout (37-Pin, D-Type)"**). If using the dsPICDEM MC1 Motor Control Development Board, this signal is routed to pin 14 of the 30F6010 dsPIC device, which is on Port RE9. The minimum pulse width for the RESET is 2 μs. The RESET should be done in coordination with the SPI™ handling routine of the dsPIC device to ensure correct synchronization of the serial interface providing the isolated voltage feedback (see **Section 1.2.6.2 "Isolated Feedback"** and **Section 1.4.7.2 "Isolated Voltage Feedback"**). The system is now ready to use.

1.2.4.2 POWER-DOWN SEQUENCE

- Stop firing all power devices.
- Turn off the incoming AC supply.
- Wait until the red DC bus LED indicator visible through the ventilation holes in the top of the unit has gone out (this will take 3 minutes or less).
- Turn off the power supply feeding the control card (if required).

1.2.5 Power Device Switching Frequencies

The PFC stage has been designed for a switching frequency of 50 kHz (±5%). This offers a good system compromise between cost, size and efficiency. The modulation frequency affects not only the losses in the power switches and diode but also that in the PFC inductor and snubbing components. The user should not deviate from the stated carrier frequency. The user should note that a typical regulation level for the DC bus is between 350-400V.

If the user does not wish to use the PFC stage the PFC switches can simply be left off. However, the PFC inductor and diode will be left in circuit and the input current will remain limited to 5A (RMS) and 8.9A Peak. The user should read **Section 1.5.3.3 "Bypassing The PFC"** if this is unacceptable.

The Brake chopper switch has been designed so that it may be switched up to a maximum frequency of 16 kHz. This frequency limit is chosen for power dissipation and low voltage power supply consumption reasons. In most braking applications a lower modulation frequency will be used, as there is little benefit (apart from acoustic noise) from modulating at such a high frequency.

The six inverter switches have been designed so that they may be switched up to a maximum frequency of 20 kHz. This frequency limit is chosen for power dissipation and low voltage power supply consumption reasons. Unless extremely low output current harmonics or very high bandwidth control is required, it is suggested that a 16 kHz carrier frequency be used. This offers lower loss while still being inaudible. It also has the advantage that the dead time insertion will cause less distortion of the output voltage.

© 2003 Microchip Technology Inc.

Given the high side and low side switches of the inverter are connected in series across the DC bus (see Figure 2.1), both switches should never be turned on at the same time. Turning both switches on effectively places a short circuit across the DC bus and is called “Shoot Through”. Shoot Through should be avoided at all costs. In order to avoid Shoot Through, an appropriate time delay must be inserted between the turn off command to one device and the turn on command to the other device of the same inverter leg. This time is called the “Dead Time”. The required Dead Time depends on the switching speeds of the power devices and the timing delays due to the optocouplers and the gate drive circuits.

Note: No hardware Dead Time is included in the design as it is included as a feature of the Motor Control PWM Module of the dsPIC device. A minimum Dead Time of 2 μs should be used. This applies to both turn on and turn off of both devices.

Writing to the appropriate registers in the dsPIC device (DTCON1 and DTCON2) sets the dead time. Refer to the *dsPIC30F Family Reference Manual* (DS70046) for details.

Although not necessary for correct operation of the system, it is common practice to eliminate very narrow firing commands. This is because they will have negligible effect on the output waveform but incur additional switching loss. It is suggested that a duty cycle that gives transistor on or off times of less than 100 ns be eliminated by rounding the duty cycle up or down as appropriate. Note that pulses, which are narrower than the dead time set in the Motor Control PWM Module, are automatically eliminated.

Note: The user should verify that all PWM frequencies and dead time settings are correct using an oscilloscope before connecting the control signals to the power module.

In order to provide an economic design, so-called bootstrap power supplies are used for the high side inverter switches (see **Section 1.4.3.3 “Gate Drive”** for details). As the charging path for these is only made when the corresponding low side switch or diode conducts, this places some minor restrictions on modulation. These are as follows:

1. When the power module is first energized after a period of time where no modulation has taken place, all low side switches should be turned on for 2-3 μs. This ensures the bootstrap supplies are “primed”. This can be simply done by using the output override facility in the dsPIC Motor Control PWM module by setting the correct bits in the OVDCON register. Care should be taken to ensure a shoot through does not accidentally occur. The possibility of a shoot through fault will be minimized if the dsPIC PWM module is operated in the complementary Output mode (module default).
2. If the user is continuously modulating all the low side switches as part of their PWM strategy, the “priming” step is not strictly necessary, as it will happen automatically. There will however be a delay of variable duration before the high side switches actually fire. The delay will depend on the particular operating circumstances and whether it is acceptable or not will depend on the particular application.
3. In extreme circumstances, it is possible that the high side bootstrap supply will discharge while the system is running. This will not happen for typical sinusoidal modulation schemes provided an inductive load (e.g., a motor) is connected. If a bootstrap supply collapses, an under-voltage lockout will automatically occur to protect the high side switch entering the linear region of operation. The high side switch is turned off whatever the command. The lockout is automatically cleared when the bootstrap supply is restored and the next turn-on edge occurs. If necessary, the user should periodically apply a refresh pulse to the low side switch in a similar manner to that described for priming above.

© 2003 Microchip Technology Inc.

1.2.6 Power Module Feedback Signals

1.2.6.1 INTRODUCTION

The power module may be operated in two distinct ways with respect to signal isolation. This effects which of the feedback signals are available. All feedback signals are preconditioned and scaled within the power module. Which particular set of feedback signals the user requires will change depending on the application. Typically industrial applications tend to use isolated signals for both safety, noise and performance reasons. More cost-sensitive applications, and especially those that have little or no user input, tend to run the control electronics live and use non-isolated feedback signals.

1.2.6.2 ISOLATED FEEDBACK

Table 1-2 gives the scaling of the isolated feedback signals as the system is delivered.

TABLE 1-2: ISOLATED SCALING

Feedback Signal	Scaling
Inverter Output (R and Y) Hall Current Sensor	2.4 A/V with 2.5V = 0A
DC Input Hall Current Sensor	4.8 A/V with 2.5V = 0A
DC Bus Voltage via SPI™ Channel	230 = 410V (1LSB = 1.78V)
Rectified AC Voltage (|VAC|) via SPI Channel	230 = 369V (1LSB = 1.60V)

1.2.6.3 NON-ISOLATED FEEDBACK

As the system is delivered, access is not given to the non-isolated feedback signals to ensure user safety. If an experienced user wishes to access these signals they should read **Section 1.4 "Detailed Description of Operation"** along with **Section 1.5.3.4 "Accessing the Additional (non-isolated) Feedback Signals"**. Note that once the isolation barrier is bridged, all signals can no longer be considered to be isolated from the power circuit. When operating in the non-isolated configuration, the Hall current sensors and SPI voltage feedback signals are also available.

The scaling for the signals as the system is delivered is given below. For details of changing the scaling, see **Section 1.5.3 "Changing Current Feedback and Trip Scaling"**.

TABLE 1-3: NON-ISOLATED SCALING

Feedback Signal	Scaling
R, Y, B Inverter Leg Shunts	2.4 A/V with 2.5V = 0A*
DC Bus Shunt	2.38 A/V with 2.5V = 0A*
Brake Chopper Shunt	1.09 A/V
DC Bus Voltage	91.0 V/V
|VAC| Voltage	81.9 V/V
R. Y, B Inverter Output Voltages	92.0 V/V

* If a large rate of change of current occurs due to the use of a load with low inductance, the voltage across the self-inductance of the shunts will cause an additional shunt voltage that will add to the shunt feedback signals.

© 2003 Microchip Technology Inc.

1.2.7 FAULT Protection

The following FAULT protection is provided which automatically disables all firing independent of the inputs on the 37-pin connector.

TABLE 1-4: FAULT PROTECTION

Fault Source	Nominal Trip Level	LED Indicator
R, Y, B Bottom Switch Current	±4.8A*	Shunt Overcurrent
DC Bus Current	±4.8A*	
DC Bus Voltage	410V	Over Voltage
Brake Switch Current	+4.9A	Brake Overcurrent
Heat sink Over Temperature	65°C (150F)	Over Temperature
Isolated DC Input Current Feedback	+8.9A	Hall Overcurrent
R, Y Isolated Phase Current Feedback	±4.4A	

* If a large rate of change of current occurs due to the use of a load with low inductance, the voltage across the self-inductance of the shunts will cause trips to occur at a lower level than that stated.

To reset a FAULT, assert the ISO_RESET line of the 37-pin connector. This should be done for a minimum time of 2 μs. The RESET must be carried out in coordination with the SPI handling routine of the dsPIC device to ensure correct synchronization of the serial interface providing the isolated voltage feedback (see **Section 1.4.7.2 "Isolated Voltage Feedback"**).

Note: If SHUNT OVERCURRENT trips are occurring, but not HALL OVERCURRENT trips, this may indicate that an inverter Shoot Through is occurring. The user should immediately remove AC power from the system and check that the correct 2 μs dead time exists on the inverter firing signals using an oscilloscope.

1.2.8 Operation at Low Output Frequencies and Stall

As far as the inverter power devices are concerned, it is the instantaneous temperatures of their junctions that matter for correct operation and reliability. As the current that flows through a particular power device changes through an electrical cycle so does the loss. At high fundamental output frequencies (e.g., 60 Hz), the devices have sufficient thermal "mass" to smooth out much of the effect of the variation in loss, so that the peak device junction is due to the (much lower) average dissipation. As the output frequency reduces, the peak device junction temperature reaches the worst case loss.

It is common practice to include a stall detection algorithm in software. This is designed to not only protect the power components, but also the motor from thermal overload. As it is impractical to include stall detection in hardware that maintains flexibility for development but still provides 100% protection, it is assumed that the software in the dsPIC device provides this feature. The algorithm should monitor rotor speed and cause a system trip if the rotor speed is at or near zero for greater than an appropriate length of time while the inverter is energized. A stall trip time of 2 seconds is suggested.

© 2003 Microchip Technology Inc.

1.2.9 Field Weakening

If the user is operating a brushless permanent magnet motor using field weakening by employing phase advance, great care should be taken. If a FAULT trip occurs, firing will stop, and the full back EMF magnitude, due to the motor's speed, will be present on the output terminals. Should the peak of the back EMF be above the DC bus, sudden uncontrolled motor braking will occur. The DC bus will rise in an uncontrolled manner possibly causing damage to both power devices and the DC bus capacitors. A speed greater than that which would produce a peak back EMF of greater than 450V, with no field weakening, should not be used. This should adequately protect the unit. If using the auxiliary DC input, the user should check the rating of the power supply and adjust this speed accordingly or use a series blocking diode of suitable rating.

The same care should be taken with separately excited brushed DC motors if employing field weakening at high speed. If the field current were to be increased in error, a similar braking phenomenon may occur if the back EMF rises above the DC bus. The effect is likely to be less severe as a DC over-voltage will occur tripping out both the armature and field supply (assuming the field is not supplied separately). For this reason, if using a separately excited DC motor it is recommended that both the field and the armature are supplied from the unit.

1.3 CURRENT AND POWER LIMITATIONS

The maximum power and current capability of the system is dictated by the allowable temperature rise of the different components. Establishing maximum limits is not simple given the host of different ways the user may use the system. The voltage and the nature of the electrical load used both affects the dissipation that occurs. In determining the allowable limits for the power semiconductors, the following assumptions have been made:

- Heat sink is at 70°C (worst case over temperature trip point)
- Thermal resistance of the insulating thermal pad is 4°C/W

Note that the maximum power of the system will always be the lower value due to the AC input stage or the inverter output stage.

1.3.1 Inverter Output Current Limits

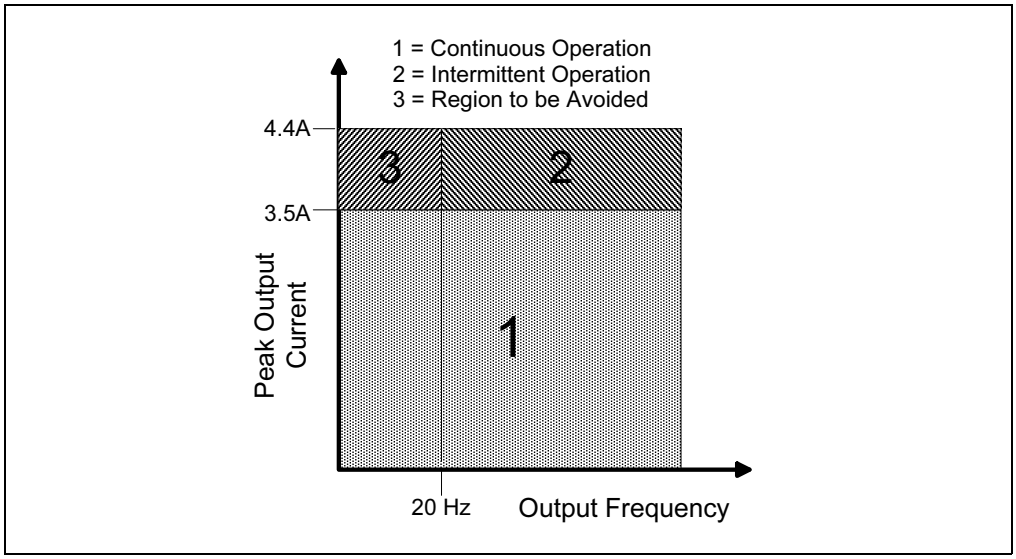
The inverter is capable of providing the full rated output of 2.5 A (RMS) within the entire operating range (voltage, temperature and at up to 20 kHz PWM carrier frequency) of the system. This includes being continuously stalled at such an electrical angle that one of the motor phases is at the peak of the rated output (3.5A) at just less than 100% duty cycle. This is a condition that causes high thermal loading because one of the inverter switches has the peak worst case conduction and switching loss continuously. Note that as far as the power devices are concerned, operation at output frequencies of less than approximately 10 Hz are equivalent to stall as far as peak device temperature is concerned because of low thermal capacitance.

In a practical application, this condition of low output frequency/stall and high duty cycle is unlikely to happen. With a motor correctly matched to the DC bus voltage, the switch duty cycle at stall will be approximately 50% thus significantly reducing the conduction loss in a particular switch. The complementary diode of the inverter phase will also conduct for approximately 50% thus spreading the conduction loss between two different power device packages. This in turn leads to a substantial reduction in device temperature.

© 2003 Microchip Technology Inc.

The user should note that the over current trip levels are set above the peak of the rated output. This is to allow modest amounts of acceleration/deceleration and to prevent nuisance trips. The user should avoid operating the system beyond the peak output of 3.5A continuously. Operation of the system just beneath the over-current trip levels at the worst case stall condition discussed above, may affect long-term reliability of the switches and should be avoided. See Figure 1-5.

FIGURE 1-5: OUTPUT CURRENT LIMITS



1.3.2 Input Current Limits Using The Active PFC

The active PFC circuit is capable of 5A RMS input (7.1A Peak) at any AC input voltage within the entire permitted operating range (voltage, temperature and 50 kHz modulation frequency).

Note:	This is only true provided the correct half-sinusoidal input current waveshape is being followed and the DC bus is being correctly regulated to be above the peak of the AC supply.

Thus, the input power and neglecting losses the output power, when using the PFC is linearly proportional to the input voltage. A commercial application will often maintain constant output power over the universal input voltage range of 88-265 VAC. This constant power characteristic was not designed into the system in order to limit the size and cost of the PFC inductor and switches.

For a fixed RMS input current of the correct half-sinusoidal shape and fixed modulation frequency, the user should note the following comments as to how different parts of the PFC circuit are thermally loaded:

- PFC inductor thermal loading is relatively insensitive to variations in AC input voltage or regulated DC bus output voltage.
- PFC switches are more heavily thermally loaded the larger the difference between the AC input voltage and the DC bus voltage (i.e., the larger the average boost ratio). This is because the average switch duty cycle increases the larger the boost ratio and therefore the switch conduction loss increases. Furthermore, the switching loss also increases slightly with boost ratio.

- For a fixed DC bus voltage, the PFC diode is more heavily thermally loaded the higher the AC input voltage. This is simply due to the increase in power throughput with higher AC input voltage due to the fixed input current. For a given AC input voltage operation at lower DC bus voltage will also load the diode more heavily thermally as the average current increases for the constant power throughput.

Note: The over current trip levels are set above the peak of the rated output. This is to allow for current ripple, modest amounts of acceleration and to prevent nuisance trips. The user should avoid operating the system beyond the peak rated output of 7.1A RMS continuously or controlling the input waveshape to be anything other than the correct half-sinusoid. Operation of the system just beneath the over-current trip levels may affect long-term reliability of the switches and should be avoided.

1.3.3 Input Current Limits when Not Using the Active PFC

If the user does not wish to use the PFC stage, the PFC switch can simply be left off. However the PFC inductor and diode will be left in circuit and the input current will remain limited to 5A (RMS) and 8.9A Peak to protect the diode. The user will also notice a large droop with increasing load when the PFC inductor is left in circuit. **Section 1.5.3.3 "Bypassing The PFC"** explains how to modify the unit to bypass the PFC diode or the whole PFC stage.

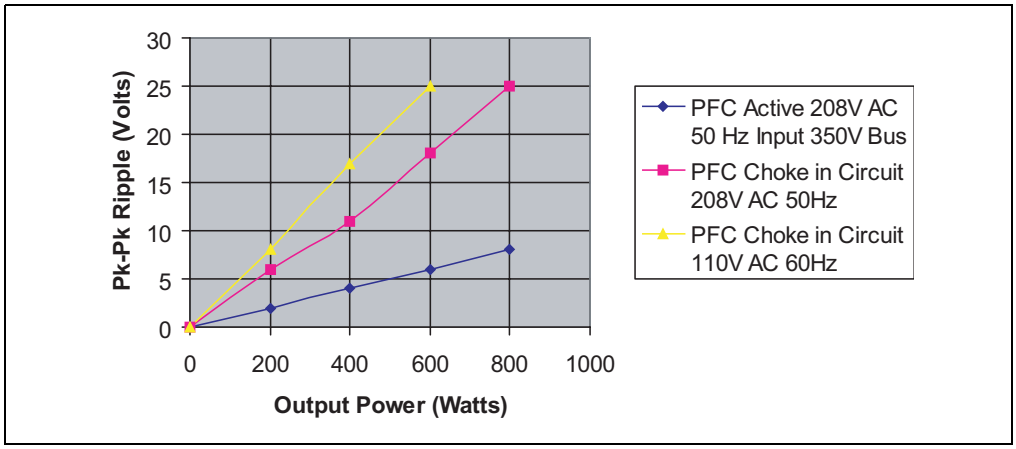
With the PFC diode removed from the circuit, the rated current increases to 6A (RMS) limited by the loss in the PFC inductor. With the PFC inductor also removed from the circuit the rated current increases to 7A (RMS) limited by the NTC soft-start thermistor and the diode bridge. Note that with the PFC inductor removed from the circuit it is possible that less input power will be possible despite the higher permitted input current. This is for two reasons. Firstly because the power factor will be lower without the PFC inductor to smooth the input current. Secondly, the DC input over-current protection will be more easily tripped by the surge of current that occurs on initial conduction of the Diode Bridge.

1.3.4 DC Bus Voltage Ripple

The unit has been designed with 3 x 330 μF DC bus capacitors in parallel thus giving approximately 1 mF of capacitance. This value is substantially more than a fitting to a commercial drive of this rating, when running off single-phase 208V AC or higher when using the PFC. Given the development nature of the system, the capacitance was oversized to assist those users wishing to use the system without the PFC or at lower voltages. Figure 1-6 gives the peak-peak DC bus voltage ripple for three different conditions.

© 2003 Microchip Technology Inc.

FIGURE 1-6: DC BUS VOLTAGE RIPPLE



Note that if operating without the PFC inductor in circuit that the DC bus voltage ripple is similar in magnitude to that shown above but the average DC bus voltage is higher for the same power.

1.3.5 Brake Chopper Output Current Limits

The brake chopper switch and diode are capable of providing the full rated output of 4A within the entire operating range (voltage, temperature and at up to 16 kHz modulation frequency) of the system. The brake chopper diode has been oversized from that usually required due to the inductance of an external braking resistor and cables so that the brake chopper is more general purpose.

Note: The user should note that the over current trip levels are set above the peak of the rated output. This is to prevent nuisance trips. The user should avoid operating the system beyond the peak output of 4A continuously. Operation of the system just beneath the over-current trip of 4.9A may affect long-term reliability of the brake chopper switch and should be avoided. The value of the brake chopper resistor should be chosen to ensure no more than 4A can flow, even at the peak DC bus voltage.

1.4 DETAILED DESCRIPTION OF OPERATION

1.4.1 AC Supply Input Stage (Appendix A, Sheet 1)

The AC supply input stage of the board consists of the following components:

- F1 – 1.25" x 0.25" 5A 250 VAC high rupture fuse – Note: only replace with part of the same rating.
- C8 – X2 class film capacitor to aid in the suppression of AC supply transients.
- R11 – A 1W high voltage resistor which acts to discharge C8.
- C9, C10 – Y class film capacitors to aid in the suppression of AC supply transients and to also provide a low impedance return path for any currents that flows from the power device tabs to the heat sink and enclosure due to capacitive coupling.
- BR1 – A single-phase bridge rectifier to convert the incoming AC into DC suitable for input to the power conditioning stage.
- V1 – A metal oxide varistor located across the incoming supply lines to suppress high energy transients.

© 2003 Microchip Technology Inc.

1.4.2 Input Power Stage (Appendix A, Sheet 1)

1.4.2.1 SOFT-START PROTECTION

- NTC1 – A resistor with a negative temperature coefficient that acts to limit the surge of input current that would occur at initial application of power due to the discharged DC bus capacitance. The initial nominal cold resistance is 5W, which reduces once current flows and the device heats up. Note that when the Power Factor Correction inductance (L1 and L2) is in circuit that the NTC also reduces the overshoot in DC bus voltage that other wise occurs on application of power.

1.4.2.2 ACTIVE POWER FACTOR CORRECTION (PFC)

The active PFC circuit is essentially a simple boost chopper with the control aimed at shaping the input current to follow the incoming mains supply waveshape. The reader is directed towards a good textbook (e.g., Power Electronics, Mohan et. al. ISBN 0-471-58408-8 pp488-494) for a detailed description of operation and control of the circuit. The purpose of the different parts of the circuit are described below:

- L1 – A high frequency axial inductor with a single layer winding on a ferrite core. This component is in series with the main inductor (L2) to reduce the effect of the self-capacitance of it's winding. Without L1, significant high frequency (15 MHz) ringing of the inductor current occurs at every transistor turn-on, which would increase EMI and the PFC transistor switching loss.
- L2 – A power inductor with two stacked toroidal cores made from a powdered-iron material to limit the core loss while maintaining good energy storage density. The particular cores used are Micrometals T200-34. A simple multilayer winding is used which results in moderate copper loss but significant self-capacitance. 142 turns of 1.12 mm diameter enameled copper wire is used. The design offers a good compromise between cost, core loss and size for this application. The nominal inductance is 1.15 mH at 5A.
- Q1, Q2 – Two 500V TO220 MOSFETs connected in parallel. As the tabs of the devices are not isolated, a thermally conductive insulator is used. When closed, Q1 and Q2 increase the energy stored in the inductor L2. When open, energy stored in the inductance is transferred to the DC bus capacitors (C3-C5). Energy is also drawn from the AC supply during this time. By appropriate control of the switches, the input current wave-shape can be profiled to obtain good power factor and low harmonic distortion.
- D1 – A 600V DO-220 diode optimized for use at high switching frequency. As the tab of the device is not isolated, a thermally conductive insulator is used.
- C1, R1, R2 – A “snubber” that acts to damp high frequency oscillations and limit the rate of change of voltage across Q1 and Q2.
- C3, C4, C5 – 450V 330 mF electrolytic capacitors which act as the main DC bus energy storage capacitors.
- C2, C6, C7 – 400V 1mF film capacitors which act to source the high frequency component of current for the PFC stage. Note that the faces of these components are not insulated.
- U19 – Microchip TC1412N gate drive IC. This contains a low resistance complementary push-pull MOSFET pair and input circuitry suitable for interfacing to a wide range of input voltages. It is an ideal choice for this application allowing up to 2A of peak gate drive current to switch Q1 and Q2 rapidly and therefore achieve low switching loss. It also has a small footprint allowing it to be located physically close to the transistors allowing a low inductance gate circuit layout.

© 2003 Microchip Technology Inc.

- C20, C21, Q11, R45, R46, R52 – These components act to provide a dynamic level shifting circuit to U19 while Q1 and Q2 switch. Inductance of the power tracking between the sources of Q1 and Q2 due to the physical board layout means there is a substantial transient voltage (up to 5V in this case) between the +15V supply * point reference at R61 and the sources of Q1 and Q2. This simple low cost circuit allows the power supply of U19 to move transiently. Q11 provides a level shift to ensure correct assertion of the firing command. In applications with fewer constraints on physical layout and/or lower switching speed requirements, these components may not be needed.

1.4.3 Phase Inverter (Appendix A, Sheet 2)

1.4.3.1 INTRODUCTION

The 3-phase inverter has three identical circuits, shown as R (RED) Y (YELLOW) and B (BLUE). These are often referred to as inverter “legs”. They invert the DC bus back to a variable AC output waveform by appropriate modulation of the switches. When a star or delta connected three-phase motor is used, the electrical symmetry can be exploited to provide bi-directional current and voltage with just three such legs. In this way, both motoring and generating/braking operation can be used in either direction of rotation, commonly called “4 Quadrant” control.

There is no reason why the user can not use two of the legs in an “H-bridge” configuration for control of DC motors or other single-phase applications requiring bi-directional current and voltage. Even a single leg could be used with just the low side switch controlled for a simple unidirectional current application (e.g., field control of a separately excited DC motor).

The detailed description of one “leg” (red phase) is given below. The other legs are identical in function.

1.4.3.2 POWER DEVICES

- Q3, Q4 – 600V N-Channel IGBT transistors with co-packaged anti-parallel 600V diodes. They are packaged in the industry standard TO220. As the tabs of the devices are not isolated, a thermally conductive insulator is used.
- The IGBTs are optimized for switching at frequencies up to 20 kHz while having improved tolerance to FAULT conditions (at the slight expense of conduction loss).
- The diodes are of the “soft-recovery” type for reduced RF emissions.
- The tracking between the devices and to the DC bus is designed to minimize the inductance that causes transient over/undershoots.
- R4 – A 3W 25 mΩ shunt resistor through which the low side switch and diode returns to the -DC bus. The shunt is used for FAULT protection and (optionally) for an alternative feedback signal – see **Section 1.2.6 “Power Module Feedback Signals”** and **Section 1.2.7 “FAULT Protection”**.

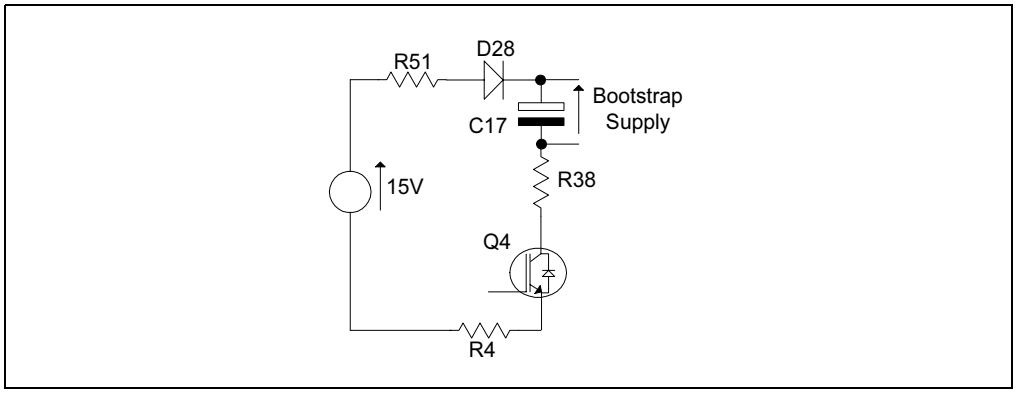
1.4.3.3 GATE DRIVE

- U22 – An integrated high voltage IC (IR 2112) which provides gate control of a low side and a high side power transistor. As the emitter of the high side device (Q3) can be at any potential between -DC and +DC, and even beyond transiently, internal circuitry must provide for the necessary level shifting to ensure correct operation. The IR2112 does this without providing isolation. The 2112 also monitors the low and high side power supplies and shuts down if an under voltage is detected. The under-voltage lockout is automatically reset by a rising edge of a firing command once a valid voltage is present. See www.irf.com for a full data sheet.

The function of groups of the discrete gate-drive components is explained below:

- R51, D28, C14, C17 – These components form a floating power supply for the high side gate driving stage of U22. Whenever the low side IGBT (Q4) or it's anti-parallel diode is conducting; a charging path for C14 and C17 is formed. This is because the 15V supply is referenced to the -DC bus and D28 conducts. When the high side switch is on, and the low side switch is therefore off, D28 blocks reverse current flow that would result from the bus voltage present on the inverter output. This kind of floating supply is usually referred to as a “bootstrap”, see Figure 1-7. This circuit is commonly used because it is both efficient and economical. It is assumed that any bootstrap initial priming or any necessary refresh is carried out in software by the dsPIC device. This is discussed in **Section 1.2.5 “Power Device Switching Frequencies”**.

FIGURE 1-7: BOOTSTRAP SUPPLY



- R33, D21, R39 and R38 – These components aid in the correct control of the gate of the high side power device. The same circuit is repeated for the low side switch using R54, D27, R57 and R58. Generally speaking, the larger value of gate resistance used, the slower the device switches. Slower switching reduces over/undershoots and consequently EMI, but increases switching loss and hence device junction temperature. Turning the device on uses R39 and R38. Turning the device off uses D21+R33 in parallel with R39 and R38. In this way, different turn on and turn off resistance can be used to optimize switching performance.
- D31 – This is a high voltage clamping diode located directly adjacent to the IC. It is necessary to ensure correct operation of the IC during extreme transients that can occur during a FAULT. In combination with R38 and R53, it ensures Pin6 of U22 never goes more than 5V negative with respect to Pin2.
- R27 and R26 – These resistors form a passive Gate Emitter pull-down to ensure the IGBTs stay off if the low voltage power supplies are not present.

1.4.4 Brake Chopper (Appendix A, Sheet 1)

Clearly, if the motor is used as a brake or generator, any average power that flows back from the inverter must have somewhere to go. As the mains input and power conditioning stages have only been designed for importing power, a means of dissipating the excess power has been provided. The most common form of brake chopper has been implemented and is described below:

- Q10 – A 600V N-Channel IGBT transistor with anti-parallel diode. This is of the same type as used for the inverter for economic reasons. In practice a slower switching device may be used which has lower conduction loss. Apart from acoustic noise reasons, there is no reason to modulate the device at high frequency. As the tab of the device is not isolated, a thermally conductive insulator is used.

© 2003 Microchip Technology Inc.

- D3 – A 8A 600V diode required to freewheel the current around the resistor due to it's inductance. As the tab of the device is not isolated, a 3W 25mΩ shunt resistor through which the low side switch and diode returns to the -DC bus. The shunt is used for FAULT protection and (optionally) for an alternative feedback signal, see **Section 1.4.6 "Shunt Feedback (Appendix A, Sheet 3)"** and **Section 1.5.3.4 "Accessing the Additional (non-isolated) Feedback Signals"**.
- U23 – Microchip TC1412N gate drive IC. This contains a low resistance complementary push-pull MOSFET pair and input circuitry suitable for interfacing to a wide range of input voltages. It has a small footprint allowing it to be located physically close to the transistor, allowing a low inductance gate circuit layout. Note that the full current drive capability of the TC1412N is not necessarily required, as high frequency modulation is not essential for a brake chopper. A less expensive TC1410N or TC1411N could be used.
- R60, R62, R67, Q12, C24, C28 – These components act to provide a dynamic level shifting circuit to U23 while Q10 switches. Inductance of the power tracking between the emitter of Q10 due to the physical board layout means there is a substantial transient voltage (up to 2V in this case) between the +15V supply star point reference and the emitter of Q10. This simple low cost circuit allows the power supply of U23 to move transiently. Q12 provides a level shift to ensure correct assertion of the firing command. In applications with fewer constraints on physical layout and/or lower switching speed requirements, these components may not be needed.
- Brake Resistor – A 50W metal clad 4K7Ω resistor mounted to the heat sink is connected to pads J7 and J8. The value of the resistor has been chosen to allow a maximum dissipation of 40W. If the user wishes to be able to dissipate more power, then an external resistor can be connected to pins 6 and 7 of the 7-pin output connector. This will operate in parallel with the internal resistor. If the user wishes to change the value of the internal resistor or disconnect it, they should read **Section 1.5.3.2 "Modifying or Removing the Internal Braking Resistor"**.

1.4.5 Isolated Current Feedback (Appendix A, Sheets 1 and 2)

In order to provide isolated current feedback, Hall effect closed loop DC current transducers (LEM LTS 6-NP) devices have been installed. These devices have the following characteristics:

- Single 5V supply with 2.5V (nominal) representing 0A
- Bipolar current sensing with ±19.2A given by 4.5V and 0.5V respectively with a single turn through the transducer.
- >200 kHz bandwidth
- 3 kV AC isolation

A detailed device data sheet can be obtained from www.lem.com.

Two such devices (U3 and U4) are installed in series with the output connections of phases R and Y. These are configured to have 4 turns through the device with LK 15 and 18 installed and an additional turn formed by the internal output leads. This gives a maximum sensed current of ±4.8A and a gain of 2.4A/V. Note that a third device is not required, as the sum of the output line currents must always be zero due to symmetry. The one exception to this is during a ground FAULT condition that is detected elsewhere.

© 2003 Microchip Technology Inc.

The third device (U2) is on the positive DC input connection from the rectifier within the input power stage (see Figure 1-1). This is configured to have 2 turns of wire through it as delivered with LK2 installed. This gives a maximum sensed current of 9.6A and a gain of 4.8A/V. U2 serves two purposes. First, is to provide the required current feedback information for controlling the active power factor correction (PFC) switches. The second purpose is to provide detection of ground current faults (i.e., when one or more of the inverter outputs become incorrectly connected to ground).

1.4.6 Shunt Feedback (Appendix A, Sheet 3)

1.4.6.1 INTRODUCTION

In many applications, the cost of isolated current transducers is prohibitive or the isolation is not required. In these instances, it is common practice to use resistive shunts. The shunts can be placed in series with the output connections but this inevitably requires the use of level-shifting and the creation of floating power supplies. Therefore, it is common to have shunts referenced to the same potential as the low voltage power supplies which is invariably the -DC bus. The disadvantage of using shunts referenced to the “low side” is that the feedback information is only available during certain portions of the PWM cycle. In order to extract the required information, the shunts must be sampled at precise intervals. This feature has been allowed for in the dsPIC device by the inclusion of sample and hold amplifiers in the ADC module that can be triggered from the PWM module (see the *dsPIC30F Family Reference Manual* for details).

On high voltage low power systems, it may be possible to use shunts of high enough value to have sufficient voltage for direct input to an ADC. More commonly, the dissipation in the shunt dictates the use of low resistance values and appropriate amplification. If too high, the voltage drop across the shunt can also cause problems for driving the power transistors. For low gains, it may be possible to use single-ended amplification. Differential amplification is required as the gains increase in order to provide a signal of sufficient quality and accuracy.

The Microchip MCP6022 (dual) and MCP6024 (quad) parts have been used in the design for providing the differential amplification. They are an ideal choice for the following reasons:

- Low power consumption (1 mA typical/amp) – this is especially important where the power supplies are derived from the DC bus with a resistor/zener network.
- Low offset voltage (0.5 mV max.).
- Rail-rail inputs and outputs.
- No gain inversion with negative inputs – this is important as it is common for the amplifier to have negative spikes on its inputs that occur during switching events due to the shunt's inductance. Gain inversion can lead to current control instability and false tripping of protection circuits.
- High gain bandwidth product (10 MHz typical) – this is often a more important factor in determining the speed of response than slew rate in this application, due to the requirements to amplify rapidly changing signals of low amplitude.

Note that in applications requiring less gain and/or slower speed of response, the MCP602/604 family offers a good alternative with even lower power supply consumption.

© 2003 Microchip Technology Inc.

1.4.6.2 INVERTER LEG SHUNT RESISTOR FEEDBACK

A shunt is located between the emitter of the low side switches (e.g., Q4) and the -DC bus in every leg of the inverter. A simple differential amplifier circuit is used as shown in Appendix A, Sheet 3. The operation of the circuit used for the RED phase leg is described below:

- U24-A – One quarter of the MC6024 op amp.
- R94, R99 and C34 – These provide a small amount of passive differential filtering. This helps to reduce input stage overloading of the op amp that would occur due to spikes of voltage produced by the shunt's self-inductance. Clearly, this has a beneficial effect on the output signal.
- R84, R85, R88 and R89 – The resistors form the differential configuration of the amplifier.
- LK5 and LK6 – These allow two different gain settings to be used by shorting out R85 and R89. Note that both links must be used together for correct operation.
- LK4 – Provision is made for either bipolar or unipolar sensing by changing this link. It changes the non-inverting input reference point between 2.5V and 0V. Bipolar sensing is required for applications using sinusoidal modulation, whereas unipolar sensing is sufficient for other applications.

Other points to note:

- No common mode filtering has been used, as the amplifier's inherent common mode rejection is sufficient and it requires tight tolerance components to be effective.
- Note that the output of the op amp is not glitch-free during switching transitions, but tracks the current rapidly. It is assumed that suitable synchronization of the sampling of the output is used to reject the glitches.
- The self-inductance of the shunts (approx. 10nH) causes an additional voltage to be produced proportional to the rate of change of current. For typical motors, this additional voltage is negligible, as the inductance is high enough to ensure a low rate of change of current. If a low inductance load is used, the effect of the additional voltage will have to be compensated for in the user's software.

1.4.6.3 DC BUS SHUNT RESISTOR FEEDBACK

In addition to the three inverter leg shunts, provision has been made to monitor the current in the -DC bus. In many applications, the information contained in this signal alone is sufficient to provide the required closed loop control. The operating range and the quality of control will dictate whether a bus shunt alone can be used. Clearly, it is the cheapest of all schemes to implement.

The current that the shunt has flowing in it at any given time depends on the state of all three inverter legs. It should be recalled that having both switches in the same leg on at the same time is not allowed. The top switch being off (Top Fire = 0) assumes a bottom switch is on. It does not matter whether the current actually flows in the switch or the anti-parallel diode. The result depends only on the magnitude and direction of the output currents, see Table 1-5.

© 2003 Microchip Technology Inc.

TABLE 1-5: DC BUS SHUNT RESISTOR FEEDBACK

Fire R Top	Phase Y Top	Phase B Top	DC Bus Shunt
0	0	0	0
0	0	1	+IB
0	1	0	+IY
0	1	1	-IR
1	0	0	+IR
1	0	1	-IY
1	1	0	-IB
1	1	1	0

From this table it is clear that bipolar sensing requires with the same scaling as that used for the inverter leg shunts. It can be seen that for the 000 and 111 conditions (which corresponds to zero output phase voltage), no information is available. This can cause considerable problems if operation at low output voltages is required when using sinusoidal modulation.

Instead of actually physically implementing the bus shunt, in this design, the signal has been derived as the sum of the three inverter leg shunts. In this way, power circuit layout was not compromised. In a commercial application, it is normal to implement all three leg shunts or the bus shunt, but not both schemes. The summing amplifier circuit used can be seen on Appendix A, Sheet 3.

1.4.6.4 BRAKE SHUNT RESISTOR FEEDBACK

Knowledge of the brake resistor current magnitude is not required for control of the DC bus voltage with a brake chopper. Only feedback of the DC bus magnitude is required. Knowledge of the brake resistor value and the applied PWM can be used to determine peak and average current flowing for thermal protection of both the resistor and the power devices. However, knowledge of the brake chopper current is useful for protection of the switch should a wiring fault occur or the resistor fail. Although a fuse could be used it is often difficult to design and expensive requiring very fast acting types. In this instance instead of a fuse, the switch current is monitored by a shunt between the emitter and the -DC bus in exactly the same way as used for the inverter. This is used for an over-current trip and is also made available as an optional feedback signal. Thus, the brake chopper can also be used as either an open or closed loop, low-side chopper for single quadrant applications. The differential amplifier circuit is shown on Appendix A, Sheet 3. See **Section 1.4.6.1 “Introduction”** for a more detailed explanation.

1.4.7 Voltage Feedback (Appendix A, Sheets 1, 6 and 7)

1.4.7.1 INTRODUCTION

Provision has been made for three different types of voltage feedback:

- DC bus voltage feedback – This is required for regulation via the brake chopper or the active Power Factor Correction (PFC) circuit. It is also used to compensate for variations in the inverter output voltages that occur due to any ripple on the DC bus and as a FAULT trip.
- Rectified mains voltage feedback (|VAC|) – This is required for synchronization and shaping of the input current by the active PFC circuit.
- Inverter output voltage feedback – As well as providing the feedback signal a comparator circuit is included for sensorless operation.

The first two of these signals are available as isolated signals, whereas the inverter output voltages are only available when the system is used in the non-isolated manner (see **Section 1.2.6.3 “Non-isolated Feedback”** and **Section 1.5.3.4 “Accessing the Additional (non-isolated) Feedback Signals”**).

© 2003 Microchip Technology Inc.

1.4.7.2 ISOLATED VOLTAGE FEEDBACK

There are many different ways that the two isolated voltage feedback signals can be provided. Clearly, the DC level must be correctly maintained while still giving sufficient bandwidth. The bandwidth is especially important for the |VAC| signal in order to ensure low harmonics are produced by the active PFC. Power supply consumption should also be as low as possible. All the above requirements can be met by the use of an inexpensive PIC® microcontroller, along with two additional low current optocouplers.

In this case, an 8-pin PIC12C671 microcontroller was chosen, as it has the necessary ADC on-board and is low cost. Full advantage could be taken of the on-board 4 MHz RC clock. Three different methods for representing the magnitude of the two signals were considered. In all cases, only two optocouplers were required.

- A serial communication interface – A simplified two-wire SPI (Clock and Data Out). It would operate as a master with the dsPIC device as the slave. Given the PIC12C671 does not have a hardware SPI module, the interface would be reproduced in software. The code latency was to be used for ADC acquisition and conversion timing. This was the method chosen and the code is given in Appendix B along with a diagram showing the transmission data cycle.

Note:	The clock and data signals for the SPI interface are inverted due to the opto-isolators. The user code should account for this by sampling the data on the falling clock edge and inverting the received data.

- Pulse width modulation at constant frequency – This was rejected partly due to concerns over distortion of the pulse width by economic optocouplers. Also, it was thought that it would not be possible to provide the required bandwidth, while maintaining the 8-bit resolution of the captured data, given the lack of a hardware PWM module.
- Frequency modulation – This was considered given that the pulse distortion by the optocouplers ceased to be an issue. However, concerns about how the bandwidth of the feedback could be maintained over the 8-bit data range led to its rejection.

The actual hardware is described below:

- U34 – The PIC12C671. Note that the PIC12C671 is reset whenever the $\overline{\text{RESET}}$ line is asserted, as this pin has been configured as the $\overline{\text{MCLR}}$. This allows correct synchronization of the SPI with the dsPIC device to be established. The $\overline{\text{RESET}}$ line must be asserted for a minimum pulse width of 2 μs.
- R12, R15, R122 – These form a potential divider so that the maximum expected voltage on |VAC|_SENSE is 4.5V.
- C43 – This acts to smooth out any noise spikes on the |VAC|_SENSE_POINT in combination with R12, R15 and R122.
- R10, R13, R14, R140, R141 – These form a potential divider so that the maximum expected voltage on BUS_SENSE is 4.5V. Note that HALF_BUS_SENSE is used by the sensorless position detection comparators (see **Section 1.4.7.3 "Inverter Output Voltage Feedback and Sensorless Detection"**).
- C57 – This acts to filter out any noise spikes on the DC bus voltage sensing circuit.
- D40, D42 – Clamping diodes to protect the PIC12C671 inputs.

- U16, U17 – Low current (1.6 mA), medium speed (1 MHz) optocouplers to provide the isolation for the clock and data lines.
- R149, R150 – Series resistors that help to set the current through the optocoupler emitters. They are sized to allow a minimum of 1.8 mA to flow.
- C64, C70 – Speed up capacitors to help reduce the effect of the optocoupler's emitter capacitance at high data rates.
- R170, R171 – Pull-up resistors for the open collector outputs of U16 and U17.

1.4.7.3 INVERTER OUTPUT VOLTAGE FEEDBACK AND SENSORLESS DETECTION

Knowledge of the actual inverter output voltage is useful for two different uses. The first is for accurately compensating for output voltage errors due to dead time and power device voltage drops. This can be especially important for high current low voltage systems with high PWM frequencies and high performance requirements. The second use is for back EMF sensing for sensorless position detection schemes for Brushless Permanent Magnet (BPM) and other types of motors.

The hardware for providing this is now discussed with reference to the RED phase. The other two phases have identical circuits.

- R20, R21 and R144 – A resistor divider chain with scaling, the same as the DC voltage feedback. The same scaling is required in order that the “back EMF crossing” detection works correctly. The scaling is such that the maximum expected output voltage will give 4.5V.
- C61 – This provides filtering of the inverter output voltage in combination with R20, R21 and R144.
- D41 – This provides a clamp to ensure R_VPH_SENSE is protected.
- U31-B – A comparator used to provide a simple sensorless position detection scheme for BPM motors. Whenever R_PH crosses half the DC bus voltage, an output transition will occur. The R_CROSSING signal is only valid during regions of the electrical cycle, where the RED phase output current is zero, so that the back EMF of the motor determines the voltage of R_VPH. Thus the scheme is only suitable for use on BPM motors where 120 degree conduction scheme is used. Careful decoding of all three crossing signals and appropriate angle interpolation is required for correct commutation. An alternative method for commutation feedback must be used near zero speed where the back EMF is insufficient for the scheme to work.
- R143, R147 – These provide a small amount of hysteresis to prevent oscillation of R_CROSSING.
- R142 – The pull-up resistor for the open-collector output of the comparator.

© 2003 Microchip Technology Inc.

1.4.8 Firing Signal Isolation and Low Voltage Power Supplies

1.4.8.1 INTRODUCTION

The choice of isolation strategy and how the low voltage power supplies are to be derived are two of the major decisions that determine the architecture of a motor drive controller. For this design, the requirement was for flexibility while maintaining user safety. It was essential that the system could work off a wide range of input voltages.

1.4.8.2 FIRING SIGNAL ISOLATION (APPENDIX A, SHEET 5)

Either optical or transformer-based isolation strategies can be used for transmitting gate firing commands. For this design, it was decided to use optocouplers, as it was possible that a particular firing command may be used for commutation as opposed to high frequency modulation. This could lead to transformer saturation at low speeds. The hardware implemented is described below:

- U6-U13 – HCPL4503 optocouplers. These parts were chosen to provide good noise immunity, while requiring low current consumption on the output side. Speed was also a consideration, so that too much delay or pulse distortion was not introduced.
- R153-R160 – Pull-up resistors for the open collector outputs of the optocouplers.
- R162-169 – Series resistors to ensure at least 18 mA flows through the emitter stage of the optocouplers. Note that the ground return is via a transistor (Q15) that allows shutdown during detection of an over-current from one of the isolated Hall effect current transducers.
- U32 and U33 – Schmitt-triggered inverters which clean up the edges from the outputs of the optocouplers.

1.4.8.3 LOW VOLTAGE POWER SUPPLIES (APPENDIX A, SHEET 5 AND 8)

The requirement for operation over a wide range of input voltage resulted in using the +5V supply coming from the control board as the power source for all the low voltage power supplies. This was true for both the isolated and live sides of the system. The power supply circuitry on the live side is described below:

- U18 – An isolating (3 kV rated) 1W unregulated DC-DC converter with 5V input and 15V (nominal) output. The +15V supply is used for the gate drive of the power devices and the comparators on the live side of the isolation barrier.
- L4 and C83: A filter to reduce the reflected ripple on the +5V supply from the control board caused by the DC-DC converter.
- L3 and C77: A filter to reduce the magnitude of the ripple on the live +15V supply.
- U5 – A 5V linear regulator for the live control circuit supplies.
- D4 – A 1A diode to protect U5 against reverse bias during power-down.
- R61 – A 0Ω resistor linking the low voltage power supply star point to the -DC bus.

© 2003 Microchip Technology Inc.

1.4.9 FAULT Protection (Appendix A, Sheets 4, 5 and 6)

1.4.9.1 INTRODUCTION

Given the development nature of the system, robust independent FAULT protection is provided on the power board rather than relying on software intervention. Five different fault categories are used to indicate a FAULT to the user. Four of the fault categories are detected on the live side. All FAULTs are latched and automatically disable all firing commands. In a commercial application using the dsPIC device, much of the hardware described below may be eliminated. In particular, the latches are not required as the Output Compare and Motor Control PWM modules both have dedicated fault inputs that can be configured to shutdown PWM outputs to their inactive state.

The operation of the fault action is described below:

- D35-D38 and R114: These form an active high wire OR of all four (live) FAULT signals. R114 provides a passive pull-down during normal operation. The resulting FAULT signal is used to directly shutdown the inverter gate drive ICs via their shutdown logic input.
- R113, Q13, R110, D34 and Q14: These components act to shutdown the PFC and brake chopper during a FAULT. Q14 must be on for the detector stage of their optocouplers to be powered. Under normal conditions, D34 and R110 provide the base current for Q14. If the FAULT line is asserted, causing Q13 to turn on, or if the +15V supply drops below approximately 10V, then Q14 turns off.
- U15 and R151: If FAULT is asserted, current flows via R151 to cause the (open-collector) output of U15 to turn on. This indicates back to the isolated side that a FAULT has occurred on the live side.
- R176 and Q15: If a Hall over-current is detected on the isolated side, the base current for Q15 that normally flows via R176 is removed. As all the firing command optocoupler emitters return via Q15, when Q15 is off, no firing can take place.
- D43, D44 and R172: These form an active low wire OR of the isolated and live fault indications for feedback to the dsPIC device.

1.4.9.2 INVERTER SHUNT OVER-CURRENT

The feedback signals from the inverter leg shunts and the bus current signal derived from them (see **Section 1.4.6.2 “Inverter Leg Shunt Resistor Feedback”** and **Section 1.4.6.3 “DC Bus Shunt Resistor Feedback”**) are used to detect over current trips. Note that the shunts will see “shoot-through” events which bypass the Hall current sensors. The circuitry used to implement this is described below:

- U25 – A quad package comparator used for the over current threshold comparisons. Each comparator has a small amount of hysteresis (formed by R119 and R120 for example) to ensure no output chattering occurs. Note that the inverter leg shunts are compared for positive current, which is when the current is flowing in a switch. The bus shunt is compared for a negative value to protect against faults during braking/generating. R109 forms the pull-up for the open collector outputs of U25. A small amount of filtering is used (e.g., R118, C45) to prevent spikes on the shunt signals causing false trips.
- U27-B – A remaining Op Amp package used to generate the HIGH_REF (+4.5V) from the Microchip MCP1525 2v5 reference.
- U26 (A and B) – Two, two-input NAND gates configured as a SET dominant SR flip-flop. The SET dominance is important to ensure correct fault action even if the RESET input is active.
- D5, R202 – An LED and its associated current limiting resistor for the visual indication of the FAULT.

© 2003 Microchip Technology Inc.

1.4.9.3 DC BUS OVER-VOLTAGE

The feedback signal derived for the DC bus voltage (see **Section 1.4.7 "Voltage Feedback (Appendix A, Sheets 1, 6 and 7)"**) is used to detect an over-voltage condition. The threshold is set at approximately 410V in order to protect the power devices and the DC bus capacitors. A similar circuit as described in **Section 1.4.9.2 "Inverter Shunt Over-current"** is used.

1.4.9.4 BRAKE OVER-CURRENT

The feedback signal derived from the brake chopper shunt is used to detect an over-current. The threshold is set at 6.1 A. The circuitry used to implement the trip is similar to that described in **Section 1.4.9.2 "Inverter Shunt Over-current"**.

1.4.9.5 HEAT SINK OVER-TEMPERATURE

To protect the power devices from thermal overload, a heat sink temperature trip is included. The trip temperature is set at nominal value of 65°C (150F) The circuitry used to implement this is described below:

- U1 – A Microchip TC622EAT temperature trip IC. This IC only requires an external resistor (R34) to set the nominal trip temperature. As the version chosen is packaged in a TO220, this is easily mounted along with the other power devices to the heat sink. This ensures excellent thermal coupling. As the tab of the device is not isolated, a thermally conductive insulator is used.
- R116 and C42 – These filter the output of U1 to prevent false tripping due to noise.
- Latching and indication is identical to that described in **Section 1.4.9.2 "Inverter Shunt Over-current"**.

1.4.9.6 HALL OVER-CURRENT

The signals from the three Hall effect current transducers are used to provide protection against overload, wiring and earth (ground) faults. The two inverter output Hall effect sensors (U3 and U4) are checked for both positive and negative current. The DC input Hall effect sensor (U2) is only checked for positive current for obvious reasons. The circuitry to implement the trip is shown on Appendix A, Sheet 6. Being similar to that described in **Section 1.4.9.2 "Inverter Shunt Over-current"**, it requires little further explanation. The one difference is that the input signals to the comparator are divided down in order to stay within the input voltage limitations of the comparators when running from +5V.

© 2003 Microchip Technology Inc.

1.5 MODIFYING THE BOARD

1.5.1 Introduction

Certain modifications have been allowed for in the design of the system, as described below. Clearly, any additional modifications that the user chooses to make can not be guaranteed to be functional or safe. It is assumed that relevant qualified personnel only will use the system.

1.5.2 Accessing The System

Before removing the lid of the system, the following procedure should be rigidly followed:

- Turn off all power to the system.
- Wait a minimum of 3 minutes so that the internal discharge circuit has reduced the DC bus voltage to a safe level. The red LED bus voltage indicator visible through the top ventilation holes should be out.
- Verify with a voltmeter that discharge has taken place by checking the potential between the + and - DC terminals of the 7-pin output connector before proceeding. The voltage should be less than 10V.
- The system is now safe to work on.
- Remove all cables from the system.
- Remove the screws fixing the lid to the chassis and heat sink on the top and bottom.
- Slide the lid forwards while holding the unit by the heat sink.

1.5.3 Changing Current Feedback and Trip Scaling

Provision has been made to change the current feedback scaling of both the isolated Hall effect transducers and the inverter leg and bus shunts. As the trip levels are set at a fixed voltage, changing the feedback scaling also changes the trip levels. Changing the scaling is accomplished in the following way:

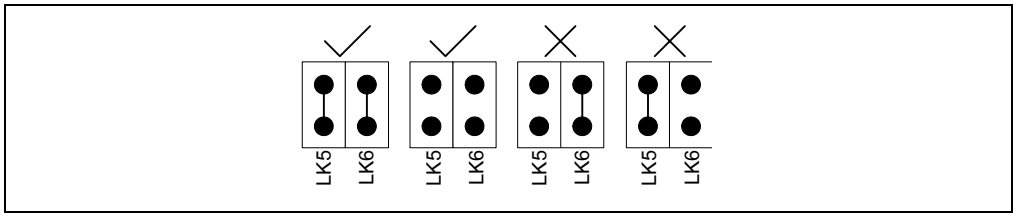
- Follow the procedure given in **Section 1.5.2 “Accessing The System”** for accessing the unit.
- Changing the inverter leg shunt sensing between unipolar and bipolar is accomplished with LK4. LK4 is located directly under the “Danger High Voltage” label on the PCB as shown in Section 9. Table 1-6 shows the settings:

TABLE 1-6: SHUNT FEEDBACK POLARITY SELECTION

LK 4 Setting	Feedback Range
1-2	Bipolar
2-3	Unipolar

© 2003 Microchip Technology Inc.

- Two different gain settings for the inverter leg shunt and DC bus shunt feedback are implemented via LK5-12. These are located directly under the “Danger High Voltage” label on the PCB as shown in Section 9. The user should consult the schematics in Appendix A, Sheet 3 to establish which links correspond to which signal. Note that links must be changed in pairs (e.g., LK5 and LK6 together or LK7 and LK8 together, etc.) for correct operation. See below.



- The scaling and trip levels for the inverter leg shunt signals are shown in the Table 1-7:

TABLE 1-7: INVERTER LEG SHUNT SCALING SELECTION

	Links Open		Links Shorted	
	Bipolar	**Unipolar**	**Bipolar**	**Unipolar**
Scaling (A/V)	1.09	1.09	2.4	2.4
Trip Level (A)	±2.2	4.9	±4.8	10.8

Note: The shaded setting should not be used, as it will not adequately protect the power devices from thermal overload.

- The Scaling and the Trip Levels for the bus shunt signal is given in Table 1-8:

TABLE 1-8: BUS SHUNT SCALING SELECTION

	Links Open	Links Closed
Scaling (A/V)	1.08	2.39
Trip Level (A)	±2.2	±4.8

- Changing the Hall sensors scaling is accomplished via solderable links (e.g., LK1, LK2 and LK3 for U1). These are located adjacent to the transducers. The links change the number of turns that pass through the transducer over a 3:1 range. Tinned copper wire of a suitable current rating should be used. **Only one link at a time should be used or unpredictable current scaling will occur.** The user should ensure that the maximum length of lead protruding below the PCB is 4 mm for voltage clearance reasons. The scaling and corresponding trip levels for U2 are shown in Table 1-9.

TABLE 1-9: HALL EFFECT BUS CURRENT TRANSDUCER SCALING SELECTION

	LK 3 Closed	LK2 Closed	LK1 Closed
Scaling (A / V)	3.2	4.8	9.6
Trip Level (A)	±5.9	±8.9	±17.8

- If the user has bypassed the PFC diode or even the entire PFC section (see **Section 1.5.3.3 "Bypassing The PFC"**) then LK1 for U2 may be used to allow higher peak input currents while still ensuring ground FAULT protection is active. Alternatively if the user wishes to develop a low power PFC application, then LK3 may be used for improved feedback sensitivity.
- The scaling of U3 and 4 is different from that shown above. This is because the output leads are also passed through the transducers thereby giving an additional turn for increased sensitivity. The scaling and trip levels for U3 and U4 are shown in Table 1-10.

TABLE 1-10: INVERTER LEG CURRENT TRANSDUCER SCALING SELECTION

	LK 15/18 Closed	LK14/17 Closed	LK13/16 Closed
Scaling (A / V)	2.4	3.2	4.8
Trip Level (A)	±4.4	±5.9	±8.9

Caution: Owing to thermal limitations of the inverter power devices, the user should be very careful about changing the scaling of U3 and 4. If the user has robust current regulation and stall detection software then LK14 and LK17 may be used to allow higher output currents. However the power devices will only be sufficiently cooled if PWM duty cycles do not exceed 75% below 10 Hz fundamental output frequency. Under no circumstances should LK13 and LK16 be used, as adequate thermal protection of the power devices is not provided.

- Once the modification is complete, install the lid ensuring all the screws are replaced.

1.5.3.1 CHANGING VOLTAGE FEEDBACK AND TRIP SCALING

The voltage feedback scaling is configured for the maximum range of input voltages. If the user requires full ADC resolution at lower voltages, then this can easily be accomplished by changing the high voltage resistors mounted on the top of the PCB.

- Follow the procedure given in **Section 1.5.2 "Accessing The System"** for accessing the unit.
- To change DC bus voltage scaling, modify R10, R13, R14. Note, if using the back EMF crossing detection circuitry (see **Section 1.4.7.3 "Inverter Output Voltage Feedback and Sensorless Detection"**), the user should also change the phase voltage feedback resistors to ensure consistent scaling.
- To change |VAC| voltage scaling modify R12 and R15.
- To change phase voltage scaling modify R16-R20.
- In all cases, it is suggested that the changes be made from the top of the board. If new component legs are inserted, these should be cropped to ensure that the maximum length of lead protruding below the PCB is 4 mm.
- Once the modification is complete, install the lid ensuring all the screws are replaced.

© 2003 Microchip Technology Inc.

1.5.3.2 MODIFYING OR REMOVING THE INTERNAL BRAKING RESISTOR

The type of braking resistor installed on the heat sink allows a maximum continuous dissipation of 50W, but can tolerate many times this power level for short periods. The value installed as standard only allows a maximum dissipation of 35W owing to its high resistance. If the user wishes to change the resistor to a lower value or remove the resistor completely as they are using an external resistor, then they should follow the procedure given below.

- Follow the procedure given in **Section 1.5.2 "Accessing The System"** for accessing the unit.
- De-solder or cut the wires to J7 and J8. This can be done from the top of the PCB.
- Undo the screws attaching the resistor to the heat sink and remove the resistor and its wiring.
- If not fitting a new resistor, proceed to the last step.
- Make up a wiring assembly for the new resistor with similar lead lengths and the terminals protected with heat shrink sleeving. Ensure the wire has sufficient current and voltage rating (600V).
- Apply a thin, even coating of thermally conductive heat sink compound (e.g., Dow-Corning 340) to the back of the resistor.
- Fit the resistor to the heat sink and solder the wires into J7 and J8. Ensure the leads are cropped so that the maximum length of lead protruding below the PCB is 4 mm.
- Once the modification is complete, install the lid ensuring all the screws are replaced.

Note that if the user fits a lower value of internal resistor to allow higher transient dissipation, then the user's software must ensure adequate thermal protection for the resistor. Failure to do so can cause the resistor to rupture. Consult the manufacturers data sheet carefully.

1.5.3.3 BYPASSING THE PFC

If the user does not require the use of the active Power Factor Correction, all the user needs to do is not fire the PFC switch. The system will still benefit from the PFC inductor acting to smooth the input current when the rectifier is charging the DC bus capacitors. However, the PFC diode will remain in circuit. This will incur additional unnecessary loss. Provision has therefore been made to bypass the PFC in two different ways. Alternatively, the user could feed in an external DC supply using the auxiliary DC input (see **Section 1.2.2 "Making Power Connections"**). The procedures for bypassing the PFC is described below:

Keeping the PFC inductor in circuit:

- Follow the procedure given in **Section 1.5.2 "Accessing The System"** for accessing the unit.
- De-solder the wire of the large toroidal inductor marked as L2 (2) near the left-hand DC bus capacitor C4. This can be done from the top of the PCB.
- Solder the L2 wire into pad J4 ensuring that the maximum length of lead protruding below the PCB is 4 mm.
- If required, replace the input fuse with a 6-7A part of the same type (Time Lag, High Breaking Capacity and 250V or greater voltage rating).
- Once the modification is complete, install the lid ensuring all the screws are replaced.
- Note that the maximum continuous limit on input current increases to 6A (RMS) limited by the loss in the PFC inductor.

© 2003 Microchip Technology Inc.

Removing the PFC inductor from the circuit:

- Follow the procedure given in **Section 1.5.2 "Accessing The System"** for accessing the unit.
- De-solder L1. This can be done from the top of the PCB.
- Solder a wire between J4 and J6. The wire size should be 1 mm^2 (18 AWG) with a minimum voltage rating of 600V and suitable for operation up to 105°C. Note that the wire should be no longer than 75 mm (3") in length and should be cropped to ensure that the maximum length of lead protruding below the PCB is 4 mm.
- If required, change the current scaling of U2 as given in **Section 1.5.3 "Changing Current Feedback and Trip Scaling"**.
- If required, replace the input fuse with a 7-8A part of the same type (Time Lag, High Breaking Capacity and 250V or greater voltage rating).
- Once the modification is complete, install the lid ensuring all the screws are replaced.
- Note that the maximum continuous limit on input current increases to 7A (RMS) limited by the soft start NTC.

1.5.3.4 ACCESSING THE ADDITIONAL (NON-ISOLATED) FEEDBACK SIGNALS

All the non-isolated feedback signals are brought to a series of links that run along the edge of the isolation barrier. In order to access these signals, the user should rigidly carry out the procedure given below. Failure to do so could represent a safety hazard to the user as the isolation barrier is bridged.

- Follow the procedure given in **Section 1.5.2 "Accessing The System"** for accessing the unit.
- Disconnect the input wiring from the AC supply outlet.
- Wire in a safety isolation transformer with a suitable rating between the AC supply outlet and the AC input to the system. The supply to the unit should now be "floating".
- The user should satisfy themselves that the isolation transformer is wired correctly and the insulation is intact.
- Ensure that the earth (ground) continuity is maintained to the unit.
- Solder a wire between J13 and J5. The wire should be 1.0-1.5 mm^2 (18-16 AWG) with a minimum voltage rating of 600V and suitable for operation up to 105°C. It should be the standard color used for earth (ground) cabling in the user's country (e.g., green for U.S.). This link is connecting the -DC bus to the incoming earth (ground).
- In order to make the links for the non-isolated signals; it is recommended that two 0.3" pitch, 14-pin DIL resistor packages be used. These should be of the "straight-through" type with 7 independent resistors. The suggested value is 330Ω, as this will provide some ESD protection without too high of a source impedance being introduced. Note that LK28 has no circuit connections and is provided to allow the second DIL resistor package to be installed. If the user decides to fit links or individual resistors, these should be installed so that not more than 4 mm of lead protrude beneath the PCB.
- Note that all signals to and from the system are now referenced to the -DC bus that is at earth (ground) potential. The isolation transformer is providing the safety isolation. The digital 0V of the control card is permanently connected to the enclosure chassis and is therefore also referenced to ground.
- Once the modification is complete, install the lid ensuring all the screws are replaced.

© 2003 Microchip Technology Inc.

1.5.3.5 OTHER MODIFICATIONS

Clearly, there are many other modifications that an experienced engineer could make to the system. These could include:

- Changing the inverter power devices for lower voltage devices (e.g., IRF644 250V MOSFETs) if operation at low input voltages only is required.
- Changing the DC bus capacitors for higher capacitance lower voltage components.

No guarantee or liability can be accepted for any modifications that the user makes to the system. If the user removes the PCB from the enclosure chassis, they should ensure that the power device clamping force and the insulation is unaltered when the PCB is re-installed.

© 2003 Microchip Technology Inc.

1.6 TEST POINTS

The following test points are all located on the topside of the PCB. See Appendix A for references to the net names on the schematics.

Test Point	Signal Function	Net Name
TP 1	LIVE PFC Switch Firing Command (Active Low)	$\overline{\text{PFC_FIRE}}$
TP 2	LIVE Red Top Switch Firing Command	FIRE_R_TOP
TP 3	LIVE Red Bottom Switch Firing Command	FIRE_R_BOT
TP 4	LIVE Yellow Top Switch Firing Command	FIRE_Y_TOP
TP 5	LIVE Yellow Bottom Switch Firing Command	FIRE_Y_BOT
TP 6	LIVE Blue Top Switch Firing Command	FIRE_B_TOP
TP 7	LIVE Blue Bottom Switch Firing Command	FIRE_B_BOT
TP 8	LIVE Fault Indication	FAULT
TP 9	LIVE Brake Chopper Firing Command (Active Low)	$\overline{\text{BRAKE_FIRE}}$
TP 10	LIVE Serial Data from PIC12C671 for voltage feedback	LIVE_DATA
TP 11	LIVE Serial Clock from PIC12C671 for voltage feedback	LIVE_SCLK
TP 12	LIVE Divided down voltage of half DC bus	HALF_BUS_SENSE
TP 13	LIVE High reference used for FAULT trips	HIGH_REF
TP 14	LIVE Low reference used for FAULT trips	LOW_REF
TP 15	LIVE Fault Reset (and PIC12C671 $\overline{\text{MCLR}}$) line (Active Low)	$\overline{\text{RESET}}$
TP 16	LIVE +15V power supply	+15V
TP 17	Live +5V power supply	+5V
TP 18	ISOLATED High reference used for FAULT trips	ISO_HIGH_REF
TP 19	ISOLATED Low reference used for FAULT trips	ISO_LOW_REF
TP 20	LIVE Star Reference Point for Low Voltage PSUs	—

© 2003 Microchip Technology Inc.

1.7 USER SIGNAL CONNECTOR PINOUT (37-PIN, D-TYPE)

Pin	Function	Net Name	Input/ Output	Isolated
1	Not Used	—	—	—
2	Yellow Phase Shunt Current Feedback	Y_SHUNT	Output	No if LK20 installed
3	DC Bus Shunt Current Feedback	BUS_SHUNT	Output	No If LK22 installed
4	Not Used	—	—	—
5	Yellow Phase Voltage Feedback	Y_VPH_SENSE	Output	No If LK25 installed
6	Blue Phase Back EMF crossing	B_CROSSING	Output	No if LK27 installed
7	Red Phase Back EMF crossing	R_CROSSING	Output	No if LK29 installed
8	Rectifier Output Voltage (|VAC|) Feedback	|VAC|_SENSE	Output	No if LK31 installed
9	Analog +5V from control PCB (±2%)	ISO_A+5V	Input	Yes
10	PFC Switch Firing Command	CMD_PFC	Input	Yes
11	Blue Phase Top Switch Firing Command	CMD_B_TOP	Input	Yes
12	Yellow Phase Top Switch Firing Command	CMD_Y_TOP	Input	Yes
13	Red Phase Top Switch Firing Command	CMD_R_TOP	Input	Yes
14	Active Low Serial Clock	$\overline{\text{ISO_SCLK}}$	Output	Yes
15	Active Low Fault	$\overline{\text{FAULT_ISO}}$	Output	Yes
16	Yellow Phase Hall Current Sensor Feedback	Y_HALL	Output	Yes
17	PFC Hall Current Sensor Feedback	PFC_HALL	Output	Yes
18	Digital GND from control PCB	ISO_GND	Input	Yes
19	Digital +5V from control PCB (±2%)	ISO_+5V	Input	Yes
20	Blue Phase Shunt Current Feedback	B_SHUNT	Output	No if LK19 installed
21	Red Phase Shunt Current Feedback	R_SHUNT	Output	No if LK21 installed
22	Brake Chopper Switch Shunt Current Feedback	BRAKE_SHUNT	Output	No if LK23 installed
23	Blue Phase Voltage Feedback	B_VPH_SENSE	Output	No if LK24 installed
24	Red Phase Voltage Feedback	R_VPH_SENSE	Output	No If LK26 installed
25	Yellow Phase Back EMF crossing	Y_CROSSING	Output	No if LK28 installed
26	DC Bus Voltage Feedback	BUS_SENSE	Output	No if LK30 installed
27	Analog GND from control PCB	ISO_AGND	Input	Yes
28	Brake Chopper Switch Firing Command	CMD_BRAKE	Input	Yes
29	Blue Phase Bottom Switch Firing Command	CMD_B_BOT	Input	Yes
30	Yellow Phase Bottom Switch Firing Command	CMD_Y_BOT	Input	Yes
31	Red Phase Bottom Switch Firing Command	CMD_R_BOT	Input	Yes
32	Active Low Serial Data	$\overline{\text{ISO_DATA}}$	Output	Yes
33	Fault Reset Command	ISO_RESET	Input	Yes
34	Not Used	—	—	—
35	Red Phase Hall Current Sensor Feedback	R_HALL	Output	Yes
36	Digital GND from control PCB	ISO_GND	Input	Yes
37	Digital +5V from control PCB(±2%)	ISO_+5V	Input	Yes

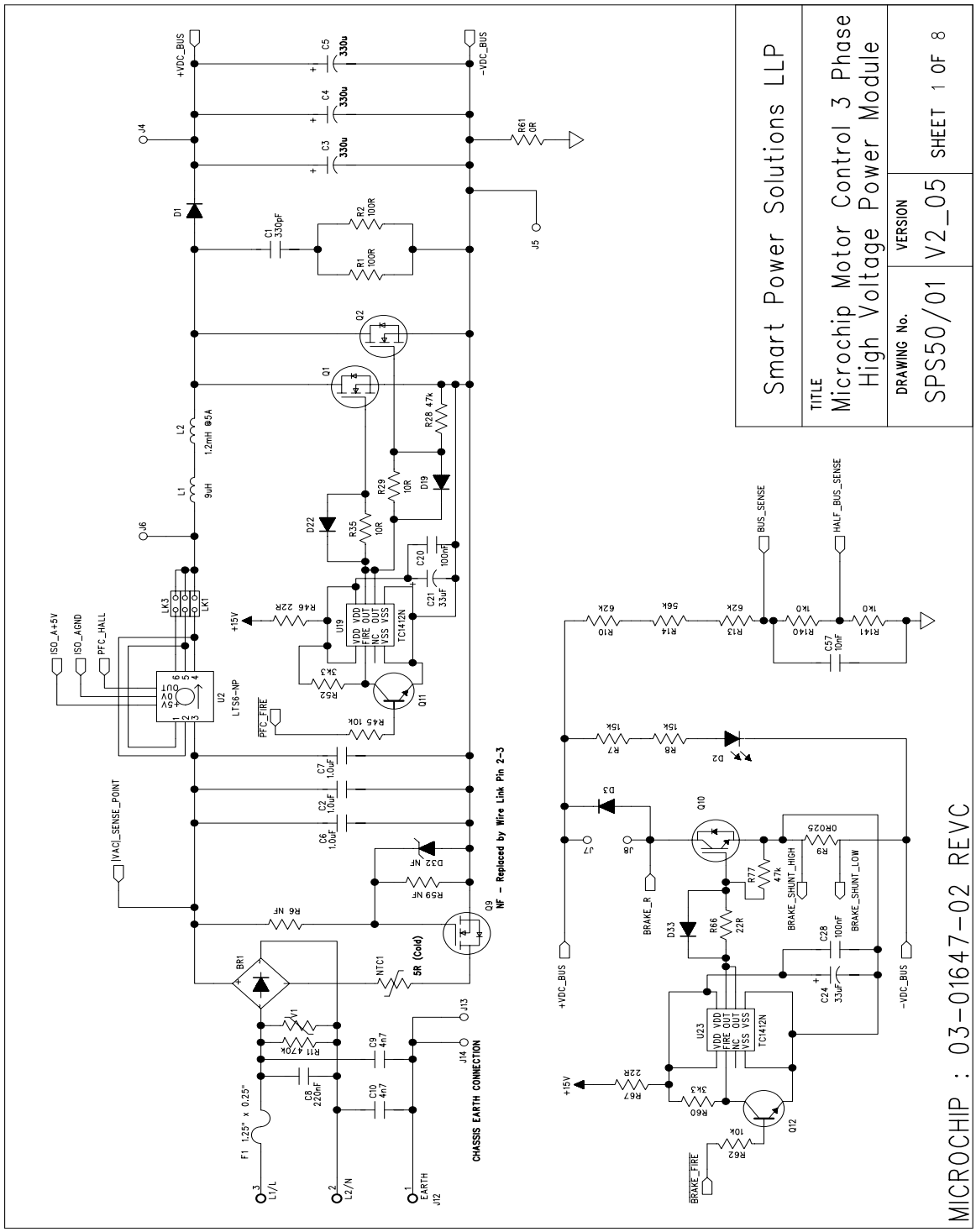
© 2003 Microchip Technology Inc.

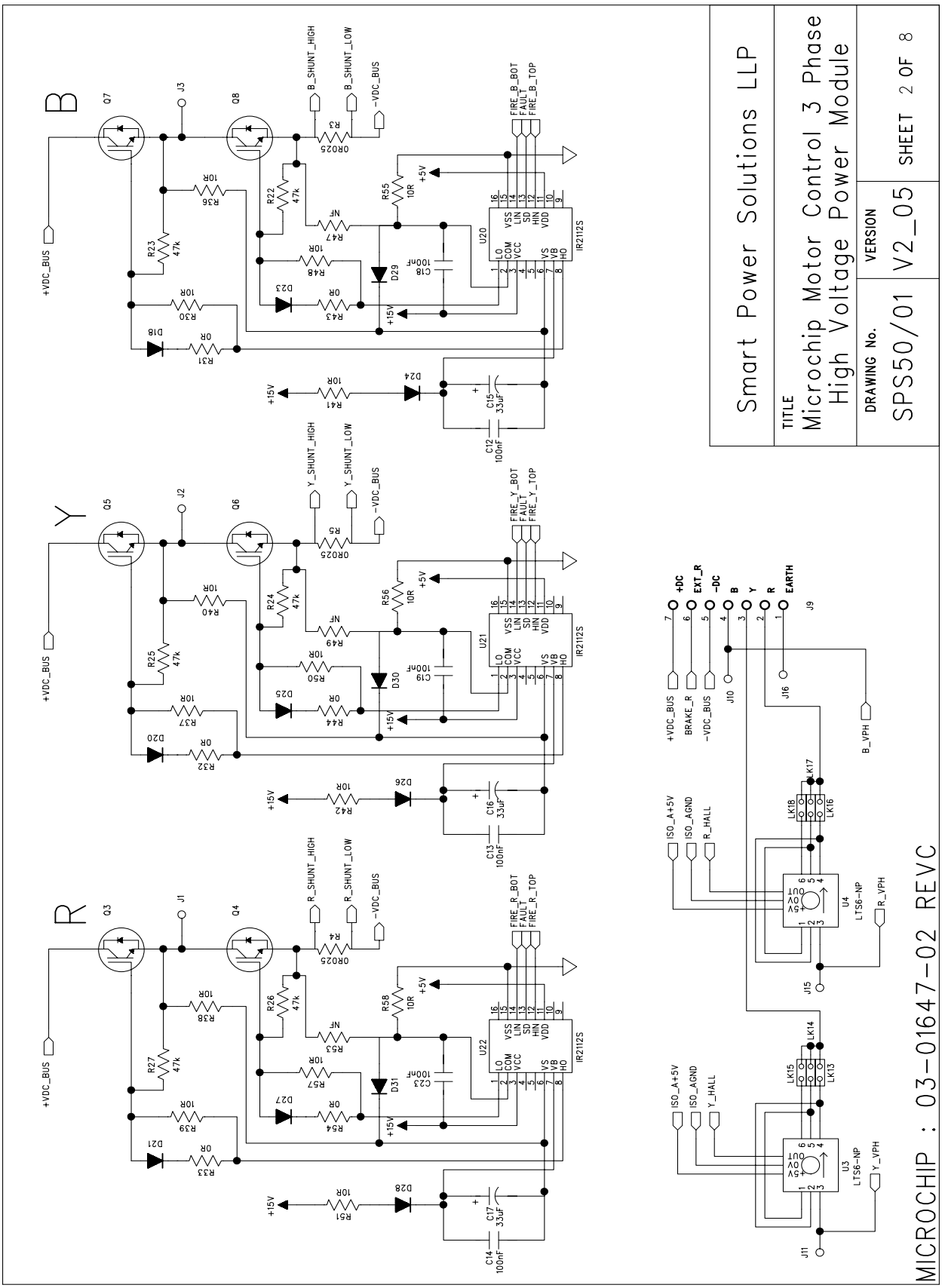
NOTES:

© 2003 Microchip Technology Inc.

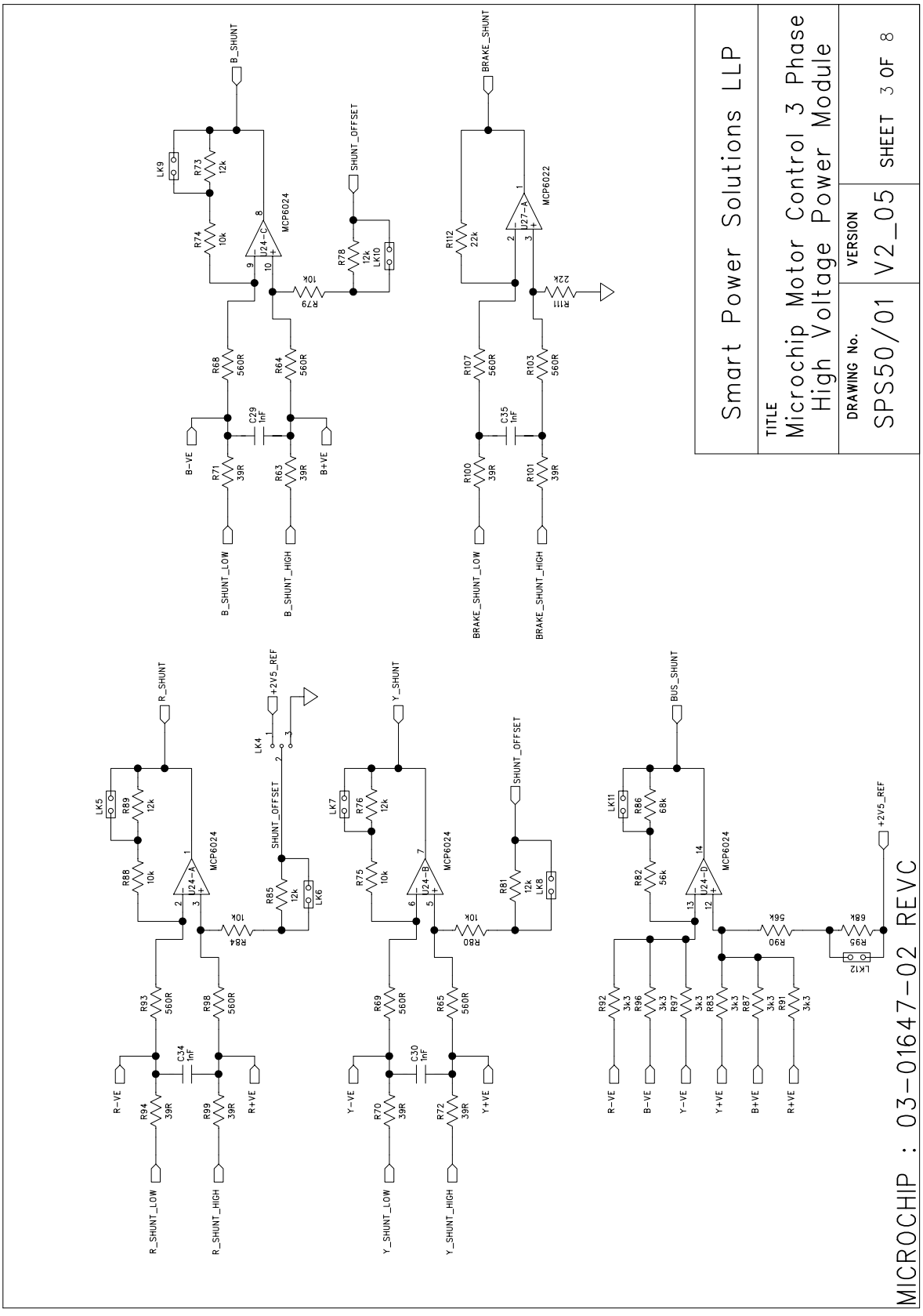
Appendix A. Circuit Diagrams

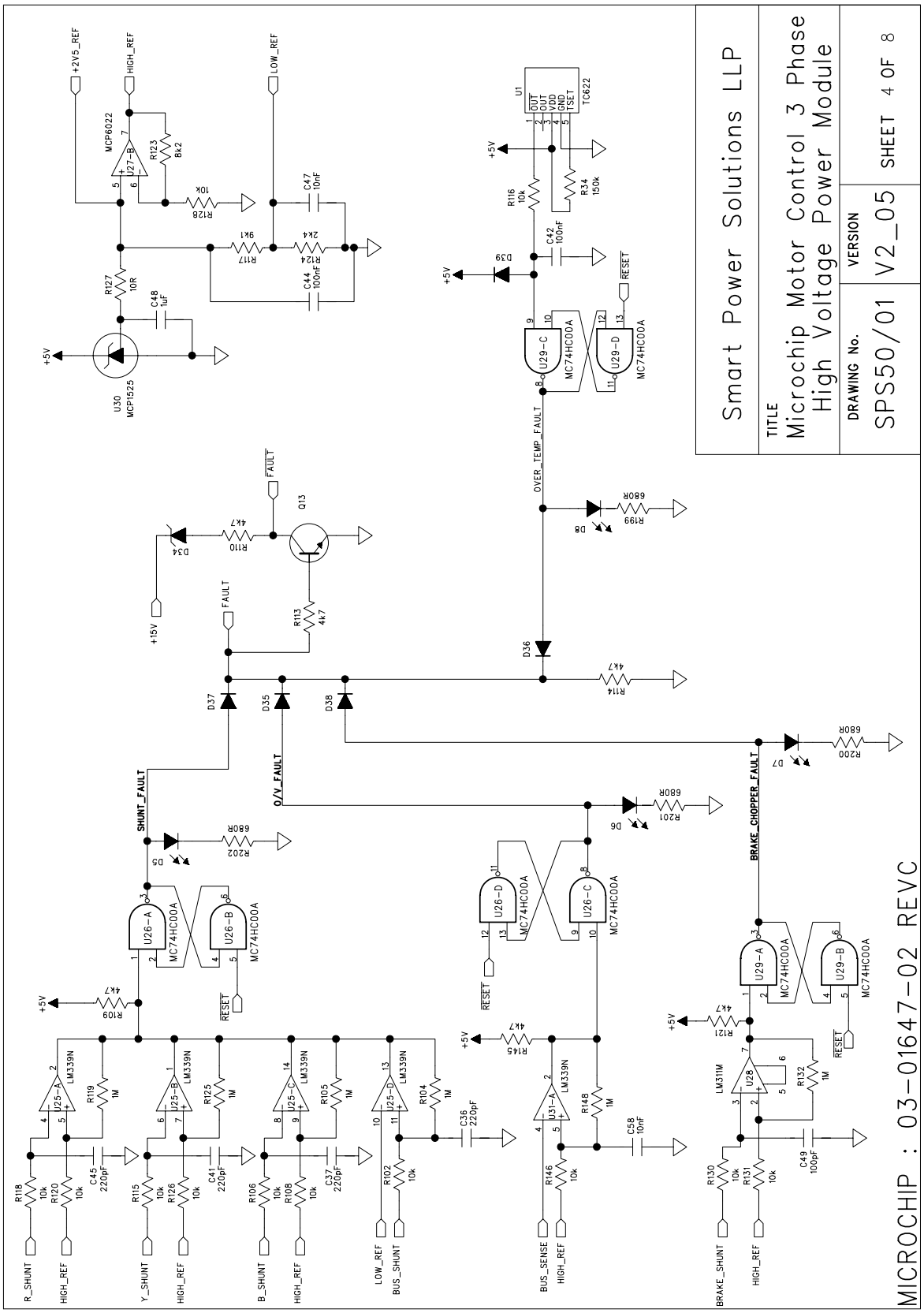
A.1 CIRCUIT DIAGRAMS



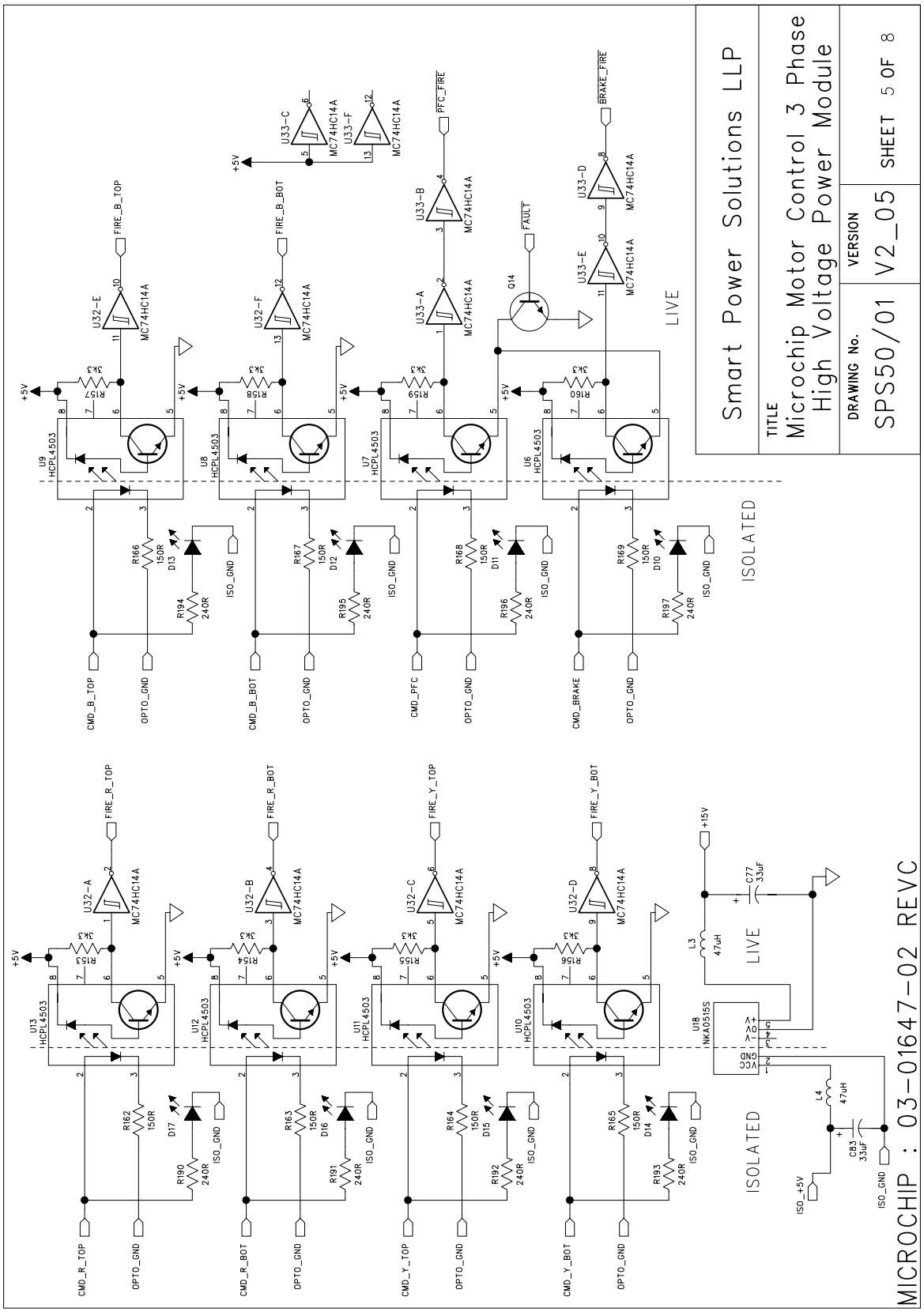


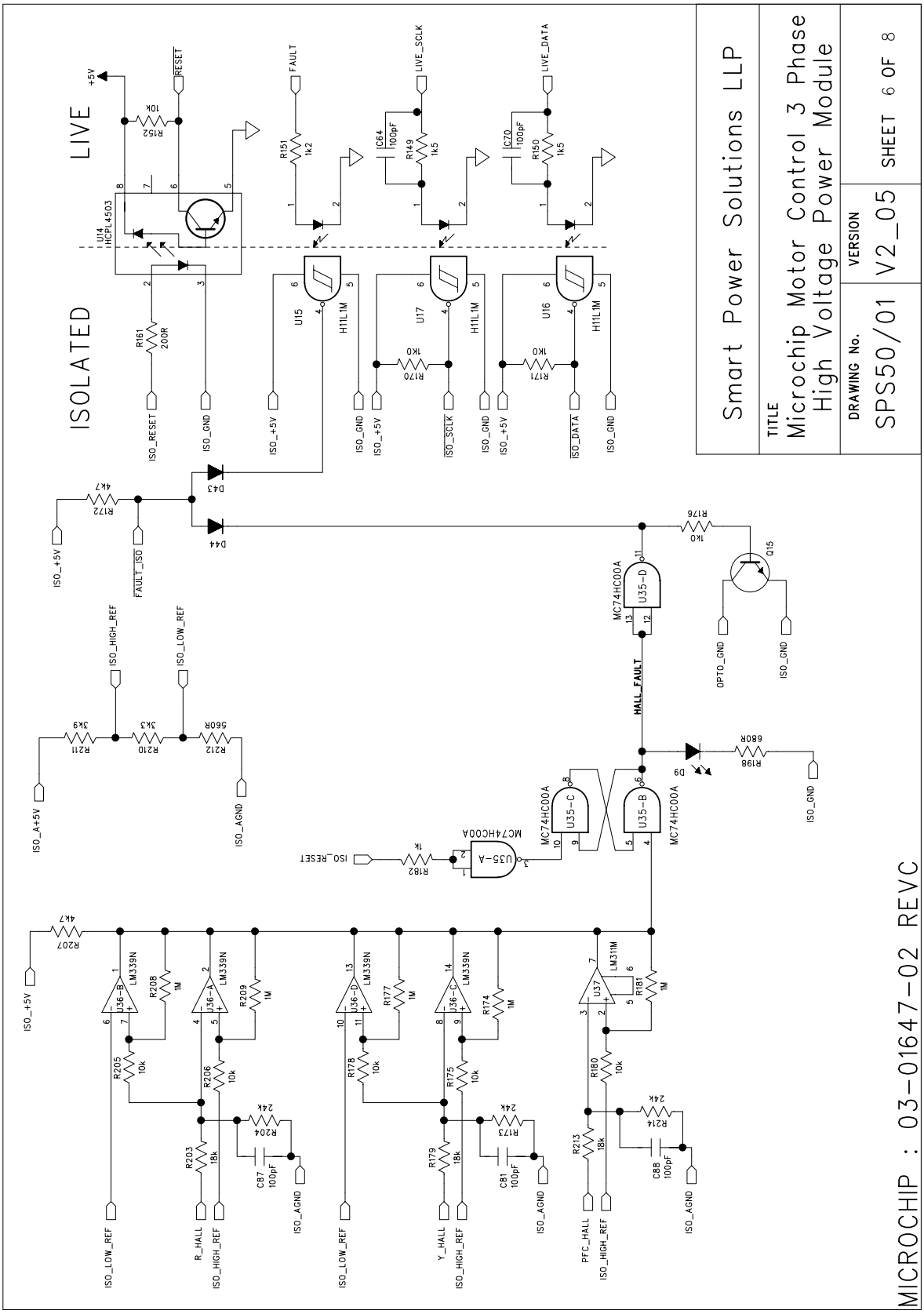
© 2003 Microchip Technology Inc.


Smart Power Solutions LLP
TITLE
Microchip Motor Control 3 Phase
High Voltage Power Module
DRAWING No.
SPS50/01
VERSION
V2_05
SHEET 3 OF 8
MICROCHIP : 03-01647-02 REVC
B_SHUNT
SHUNT_OFFSET
BRAKE_SHUNT
R_SHUNT
Y_SHUNT
BUS_SHUNT
+2V5_REF
MCP6024
MCP6022
B_SHUNT_LOW
B_SHUNT_HIGH
BRAKE_SHUNT_LOW
BRAKE_SHUNT_HIGH
R_SHUNT_LOW
R_SHUNT_HIGH
Y_SHUNT_LOW
Y_SHUNT_HIGH
R-VE
B-VE
Y-VE
R+VE
Y+VE
B+VE

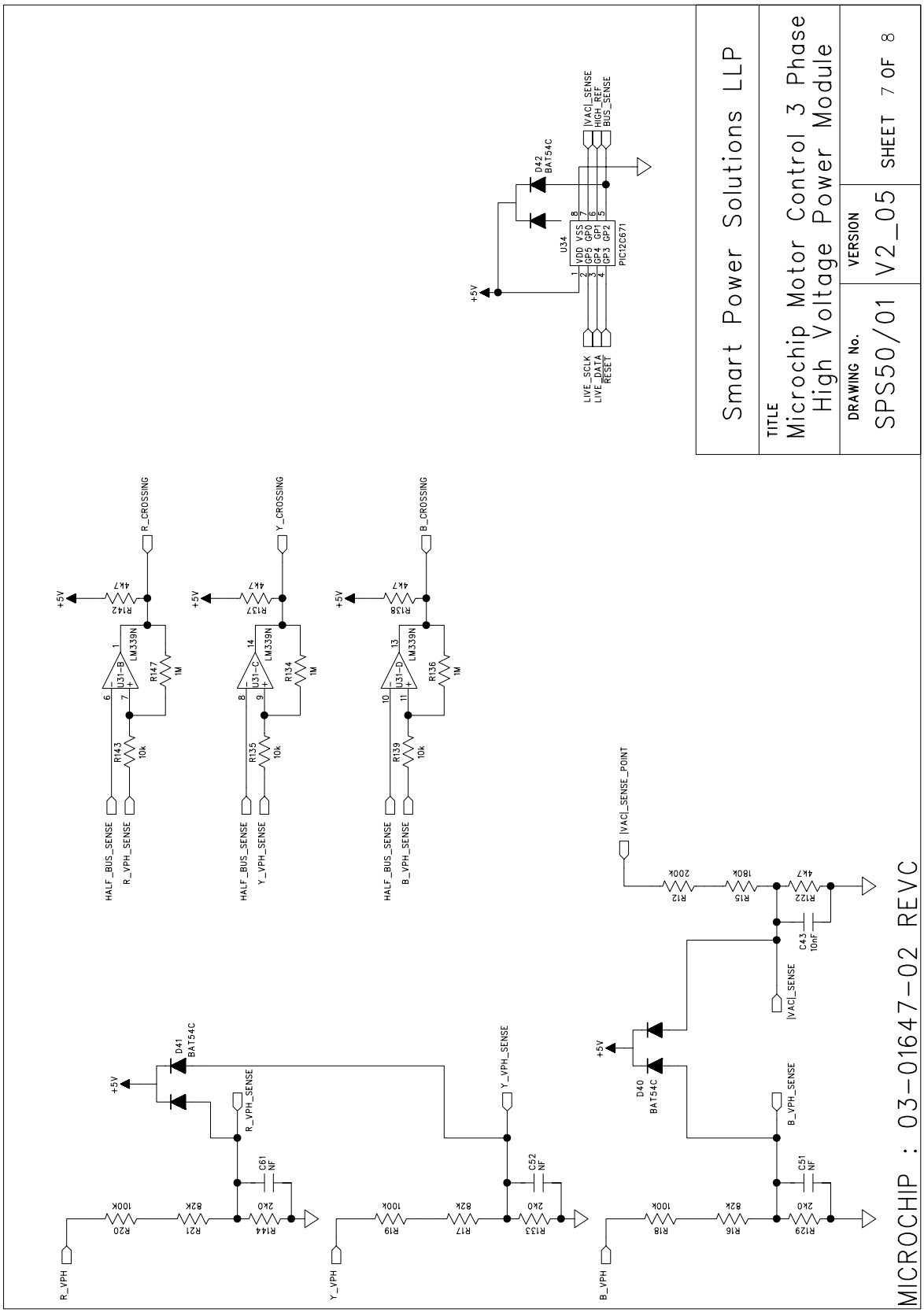


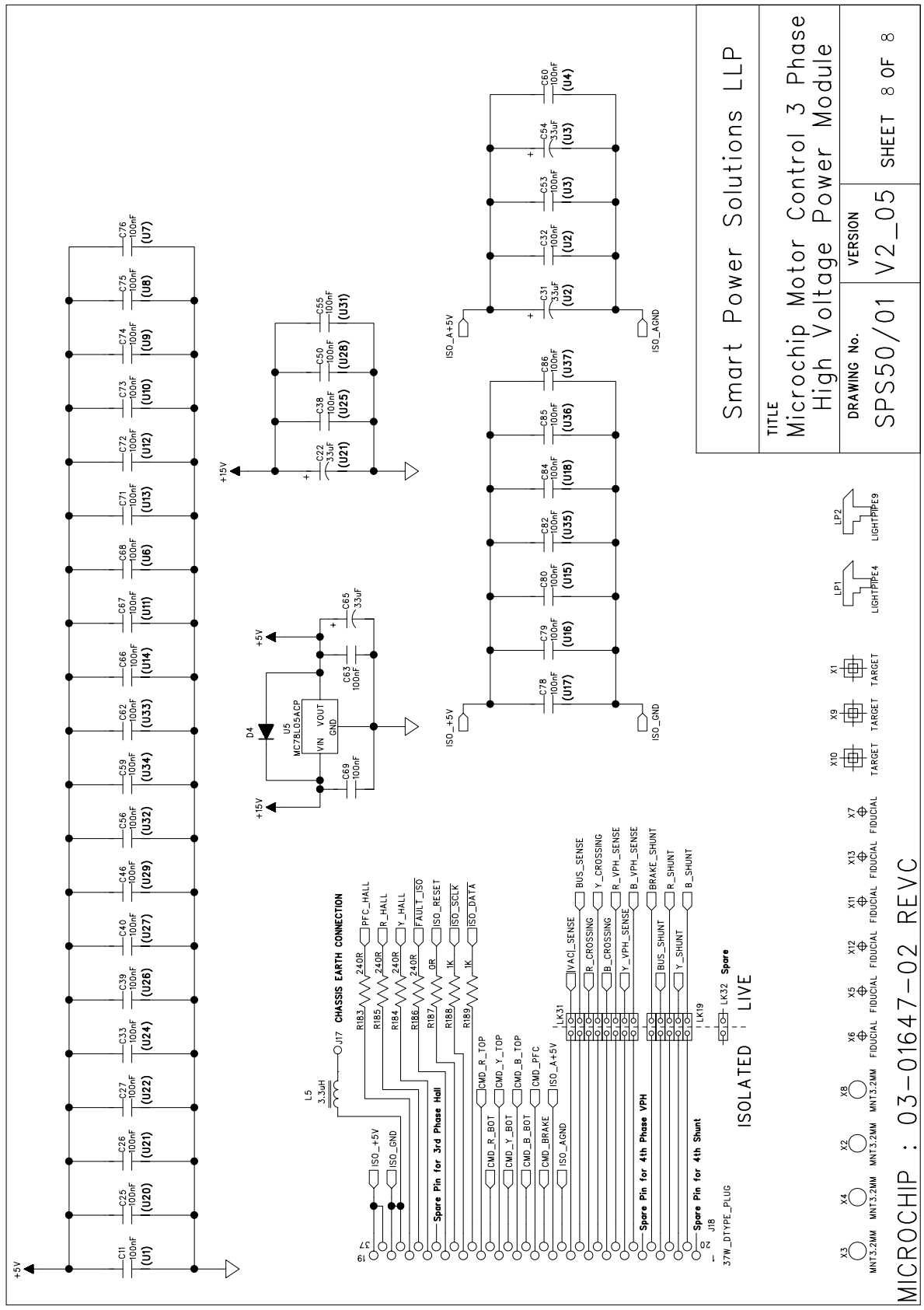
© 2003 Microchip Technology Inc.


Smart Power Solutions LLP
TITLE
Microchip Motor Control 3 Phase
High Voltage Power Module
DRAWING No.
SPS50/01
VERSION
V2_05
SHEET 5 OF 8
MICROCHIP : 03-01647-02 REVC
ISOLATED
LIVE
U9 HCPL4503
U8 HCPL4503
U7 HCPL4503
U6 HCPL4503
U13 HCPL4503
U12 HCPL4503
U11 HCPL4503
U10 HCPL4503
U32-A MC74HC14A
U32-B MC74HC14A
U32-C MC74HC14A
U32-D MC74HC14A
U32-E MC74HC14A
U32-F MC74HC14A
U33-A MC74HC14A
U33-B MC74HC14A
U33-C MC74HC14A
U33-D MC74HC14A
U33-E MC74HC14A
U33-F MC74HC14A
U18 NKA0515S
Q14
FIRE_B_TOP
FIRE_B_BOT
FIRE_R_TOP
FIRE_R_BOT
FIRE_Y_TOP
FIRE_Y_BOT
PFC_FIRE
BRAKE_FIRE
FAULT
CMD_B_TOP
CMD_B_BOT
CMD_PFC
CMD_BRAKE
CMD_R_TOP
CMD_R_BOT
CMD_Y_TOP
CMD_Y_BOT
OPTO_GND
ISO_GND
ISO_+5V
+5V
+15V
L3 47uH
L4 47uH
C77 33uF
C83 33uF



© 2003 Microchip Technology Inc.

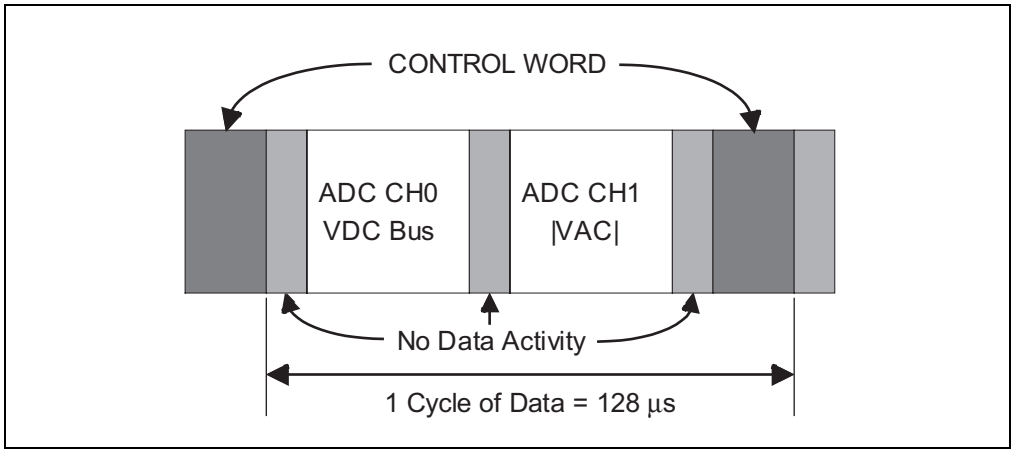

Smart Power Solutions LLP
TITLE
Microchip Motor Control 3 Phase
High Voltage Power Module
DRAWING No.
SPS50/01
VERSION
V2_05
SHEET 7 OF 8
MICROCHIP : 03-01647-02 REVC
R_VPH
Y_VPH
B_VPH
R_VPH_SENSE
Y_VPH_SENSE
B_VPH_SENSE
IVAC|_SENSE
IVAC|_SENSE_POINT
HALF_BUS_SENSE
R_CROSSING
Y_CROSSING
B_CROSSING
LIVE_SCLK
LIVE_DATA
RESET
IVAC|_SENSE
HIGH_REF
BUS_SENSE
+5V
D40 BAT54C
D41 BAT54C
D42 BAT54C
U34 PIC12C671
U31-B LM339N
U31-C LM339N
U31-D LM339N
R12 200k
R15 180k
R122 4k7
R20 100k
R21 82k
R144 2k0
R19 100k
R17 82k
R133 2k0
R18 100k
R16 82k
R129 2k0
R142 4k7
R137 4k7
R138 4k7
R147 1M
R134 1M
R136 1M
R143 10k
R135 10k
R139 10k
C43 10nF
C61 NF
C62 NF
C51 NF



© 2003 Microchip Technology Inc.

Appendix B. Source Code

FIGURE B-1: DATA TRANSMISSION CYCLE



Note: The data transmitted via the SPI interface is inverted by the opto-isolators. The user software should invert the received data.

B.1 PIC® MCU CODE AND DATA CYCLE DIAGRAM FOR SERIAL INTERFACE

```
;*********************************************************
;*  50_10_v3.ASM
;*********************************************************
;*  Smart Power Solutions LLP
;*  13th April 2003
;*  Assembled with MPLAB v6.13
;*********************************************************
;*  This program continuously converts two ADC channels, AN0
;*  & AN2 and writes the results out via SPI followed by a
;*  control word 0xF9.
;*  The software latency of the SPI transmission
;*  is used to fulfill the aquire, conversion & wait time of
;*  the ADC module for maximum data transmission rate.
;*  If transmission is corrupted, MCLR is asserted to re-sync
;*  transmission, therefore no watchdog is required.
;*  SPI clock, SCK, is GP5 pin 2 idle low and data is valid on
;*  the falling edge. SPI data out line, SDO, is PGP4 pin 3.
;*  Use config word 0xE4 when programming
;*********************************************************

      list p=12c671

      ; Include file, change directory if needed
      include "p12c671.inc"

BYTE_TO_SEND   EQU    0x20
STARTUP_TIMER  EQU    0x21
SCK            EQU    0x05
SDO            EQU    0x04


      ; Start at the reset vector
      org   0x000

Start
                        ;begin in bank0 initially
      clrf  GPIO        ;Clear GPIO

      bsf   STATUS,5    ;select bank1
      movlw 0x0f
      movwf TRISIO      ;GP5, GP4 outputs

                        ;also in bank 1
      movlw 0X02        ;AD0,AD1 and AD2 are analog channels
      movwf ADCON1      ;with VDD and VSS references

      call  0x03ff      ;factory programmed data to trim
      movwf OSCCAL      ;internal oscillator

      clrf  STATUS      ;select bank0 FOR REST OF CODE
```


© 2003 Microchip Technology Inc.

```
Initial_Capture         ;before starting SPI transmission,
                        ;aquire &convert ADC ch0, BUS_SENSE
      movlw 0x41        ;set:Fosc/8, A/D enable, ch0 select
      movwf ADCON0      ;begin sampling ch0

      movlw 0x04        ;wait for approx 20us aquisition time
      movwf STARTUP_TIMER
delay
      decf  STARTUP_TIMER,F
      btfss STATUS,Z
      goto  delay

      bsf   ADCON0,GO   ;Start A/D conversion Channel 0

finish_1st_conversion
      btfsc ADCON0,GO   ;wait for end of conversion flag
      goto  finish_1st_conversion

      movf  ADRES,W
      movwf BYTE_TO_SEND

      nop               ;extra wait before starting new aquisi-
                        tion

;*****************************************************************

Main
      movlw 0x51        ;Fosc/8, A/D enabled, ch 2 selected
      movwf ADCON0      ;begin sampling channel 2 |VAC|_SENSE

;begin to transmit value from channel 0

      bcf   GPIO,SDO    ;send bit 7
      bsf   GPIO,SCK
      btfsc BYTE_TO_SEND,7
      bsf   GPIO,SDO
      bcf   GPIO,SCK

      bcf   GPIO,SDO    ;send bit 6
      bsf   GPIO,SCK
      btfsc BYTE_TO_SEND,6
      bsf   GPIO,SDO
      bcf   GPIO,SCK

      bcf   GPIO,SDO    ;send bit 5
      bsf   GPIO,SCK
      btfsc BYTE_TO_SEND,5
      bsf   GPIO,SDO
      bcf   GPIO,SCK

      bcf   GPIO,SDO    ;send bit 4
      bsf   GPIO,SCK
      btfsc BYTE_TO_SEND,4
      bsf   GPIO,SDO
      bcf   GPIO,SCK
```

```
;start ADC convertion on ch2, which has now finished aquiring
      bsf   ADCON0,GO

      bcf   GPIO,SDO    ;send bit 3
      bsf   GPIO,SCK
      btfsc BYTE_TO_SEND,3
      bsf   GPIO,SDO
      bcf   GPIO,SCK

      bcf   GPIO,SDO    ;send bit 2
      bsf   GPIO,SCK
      btfsc BYTE_TO_SEND,2
      bsf   GPIO,SDO
      bcf   GPIO,SCK

      bcf   GPIO,SDO    ;send bit 1
      bsf   GPIO,SCK
      btfsc BYTE_TO_SEND,1
      bsf   GPIO,SDO
      bcf   GPIO,SCK

      bcf   GPIO,SDO    ;send bit 0
      bsf   GPIO,SCK
      btfsc BYTE_TO_SEND,0
      bsf   GPIO,SDO
      bcf   GPIO,SCK


finish_conversion
      btfsc ADCON0,GO
      goto  finish_conversion

      movf  ADRES,W
      movwf BYTE_TO_SEND

;need a min 4us delay before starting next acquire
;begin to transmit value from channel 2 |VAC|_SENSE

      bcf   GPIO,SDO    ;send bit 7
      bsf   GPIO,SCK
      btfsc BYTE_TO_SEND,7
      bsf   GPIO,SDO
      bcf   GPIO,SCK

;set up ADC to begin sampling channel 0
      movlw 0x41        ;Fosc/8, A/D enabled channel 0 selected
      movwf ADCON0      ;begin sampling ch0 BUS_SENSE

      bcf   GPIO,SDO    ;send bit 6
      bsf   GPIO,SCK
      btfsc BYTE_TO_SEND,6
      bsf   GPIO,SDO
      bcf   GPIO,SCK
```


© 2003 Microchip Technology Inc.

```
        bcf   GPIO,SDO    ;send bit 5
        bsf   GPIO,SCK
        btfsc BYTE_TO_SEND,5
        bsf   GPIO,SDO
        bcf   GPIO,SCK

        bcf   GPIO,SDO    ;send bit 4
        bsf   GPIO,SCK
        btfsc BYTE_TO_SEND,4
        bsf   GPIO,SDO
        bcf   GPIO,SCK

        bcf   GPIO,SDO    ;send bit 3
        bsf   GPIO,SCK
        btfsc BYTE_TO_SEND,3
        bsf   GPIO,SDO
        bcf   GPIO,SCK

        bcf   GPIO,SDO    ;send bit 2
        bsf   GPIO,SCK
        btfsc BYTE_TO_SEND,2
        bsf   GPIO,SDO
        bcf   GPIO,SCK

        bsf   ADCON0,GO   ;Start A/D conversion Channel 0

        bcf   GPIO,SDO    ;send bit 1
        bsf   GPIO,SCK
        btfsc BYTE_TO_SEND,1
        bsf   GPIO,SDO
        bcf   GPIO,SCK

        bcf   GPIO,SDO    ;send bit 0
        bsf   GPIO,SCK
        btfsc BYTE_TO_SEND,0
        bsf   GPIO,SDO
        bcf   GPIO,SCK

        nop
        nop
        nop
        nop

;while ADC is still converting Channel 0, send control word 0xF9

        bsf   GPIO,SCK    ;send bit7
        bsf   GPIO,SDO
        bcf   GPIO,SCK
        nop
        bsf   GPIO,SCK    ;send bit6
        bcf   GPIO,SCK
        nop
        bsf   GPIO,SCK    ;send bit5
        bcf   GPIO,SCK
        nop
```

```
        bsf   GPIO,SCK    ;send bit4
        bcf   GPIO,SCK
        nop
        bsf   GPIO,SCK    ;send bit3
        bcf   GPIO,SCK
        nop
        bsf   GPIO,SCK    ;send bit2
        bcf   GPIO,SDO
        nop
        bcf   GPIO,SCK
        nop
        bsf   GPIO,SCK    ;send bit1
        bcf   GPIO,SCK
        nop
        bsf   GPIO,SCK    ;send bit0
        bsf   GPIO,SDO
        bcf   GPIO,SCK


;conversion of channel 0 now complete
      movf  ADRES,W
      movwf BYTE_TO_SEND

      goto  Main        ;Do it again

      end
```


© 2003 Microchip Technology Inc.

Appendix

NOTES:

WORLDWIDE SALES AND SERVICE

AMERICAS

Corporate Office
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200 Fax: 480-792-7277
Technical Support: 480-792-7627
Web Address: http://www.microchip.com

Atlanta
3780 Mansell Road, Suite 130
Alpharetta, GA 30022
Tel: 770-640-0034 Fax: 770-640-0307

Boston
2 Lan Drive, Suite 120
Westford, MA 01886
Tel: 978-692-3848 Fax: 978-692-3821

Chicago
333 Pierce Road, Suite 180
Itasca, IL 60143
Tel: 630-285-0071 Fax: 630-285-0075

Dallas
4570 Westgrove Drive, Suite 160
Addison, TX 75001
Tel: 972-818-7423 Fax: 972-818-2924

Detroit
Tri-Atria Office Building
32255 Northwestern Highway, Suite 190
Farmington Hills, MI 48334
Tel: 248-538-2250 Fax: 248-538-2260

Kokomo
2767 S. Albright Road
Kokomo, IN 46902
Tel: 765-864-8360 Fax: 765-864-8387

Los Angeles
18201 Von Karman, Suite 1090
Irvine, CA 92612
Tel: 949-263-1888 Fax: 949-263-1338

Phoenix
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7966 Fax: 480-792-4338

San Jose
Microchip Technology Inc.
2107 North First Street, Suite 590
San Jose, CA 95131
Tel: 408-436-7950 Fax: 408-436-7955

Toronto
6285 Northam Drive, Suite 108
Mississauga, Ontario L4V 1X5, Canada
Tel: 905-673-0699 Fax: 905-673-6509

ASIA/PACIFIC

Australia
Microchip Technology Australia Pty Ltd
Marketing Support Division
Suite 22, 41 Rawson Street
Epping 2121, NSW
Australia
Tel: 61-2-9868-6733 Fax: 61-2-9868-6755

China - Beijing
Microchip Technology Consulting (Shanghai) Co., Ltd., Beijing Liaison Office
Unit 915
Bei Hai Wan Tai Bldg.
No. 6 Chaoyangmen Beidajie
Beijing, 100027, No. China
Tel: 86-10-85282100 Fax: 86-10-85282104

China - Chengdu
Microchip Technology Consulting (Shanghai) Co., Ltd., Chengdu Liaison Office
Rm. 2401-2402, 24th Floor,
Ming Xing Financial Tower
No. 88 TIDU Street
Chengdu 610016, China
Tel: 86-28-86766200 Fax: 86-28-86766599

China - Fuzhou
Microchip Technology Consulting (Shanghai) Co., Ltd., Fuzhou Liaison Office
Unit 28F, World Trade Plaza
No. 71 Wusi Road
Fuzhou 350001, China
Tel: 86-591-7503506 Fax: 86-591-7503521

China - Hong Kong SAR
Microchip Technology Hongkong Ltd.
Unit 901-6, Tower 2, Metroplaza
223 Hing Fong Road
Kwai Fong, N.T., Hong Kong
Tel: 852-2401-1200 Fax: 852-2401-3431

China - Shanghai
Microchip Technology Consulting (Shanghai) Co., Ltd.
Room 701, Bldg. B
Far East International Plaza
No. 317 Xian Xia Road
Shanghai, 200051
Tel: 86-21-6275-5700 Fax: 86-21-6275-5060

China - Shenzhen
Microchip Technology Consulting (Shanghai) Co., Ltd., Shenzhen Liaison Office
Rm. 1812, 18/F, Building A, United Plaza
No. 5022 Binhe Road, Futian District
Shenzhen 518033, China
Tel: 86-755-82901380 Fax: 86-755-8295-1393

China - Qingdao
Rm. B505A, Fullhope Plaza,
No. 12 Hong Kong Central Rd.
Qingdao 266071, China
Tel: 86-532-5027355 Fax: 86-532-5027205

India
Microchip Technology Inc.
India Liaison Office
Marketing Support Division
Divyasree Chambers
1 Floor, Wing A (A3/A4)
No. 11, O'Shaugnessey Road
Bangalore, 560 025, India
Tel: 91-80-2290061 Fax: 91-80-2290062

Japan
Microchip Technology Japan K.K.
Benex S-1 6F
3-18-20, Shinyokohama
Kohoku-Ku, Yokohama-shi
Kanagawa, 222-0033, Japan
Tel: 81-45-471- 6166 Fax: 81-45-471-6122

Korea
Microchip Technology Korea
168-1, Youngbo Bldg. 3 Floor
Samsung-Dong, Kangnam-Ku
Seoul, Korea 135-882
Tel: 82-2-554-7200 Fax: 82-2-558-5934

Singapore
Microchip Technology Singapore Pte Ltd.
200 Middle Road
#07-02 Prime Centre
Singapore, 188980
Tel: 65-6334-8870 Fax: 65-6334-8850

Taiwan
Microchip Technology (Barbados) Inc., Taiwan Branch
11F-3, No. 207
Tung Hua North Road
Taipei, 105, Taiwan
Tel: 886-2-2717-7175 Fax: 886-2-2545-0139

EUROPE

Austria
Microchip Technology Austria GmbH
Durisolstrasse 2
A-4600 Wels
Austria
Tel: 43-7242-2244-399
Fax: 43-7242-2244-393

Denmark
Microchip Technology Nordic ApS
Regus Business Centre
Lautrup hoj 1-3
Ballerup DK-2750 Denmark
Tel: 45-4420-9895 Fax: 45-4420-9910

France
Microchip Technology SARL
Parc d'Activite du Moulin de Massy
43 Rue du Saule Trapu
Batiment A - ler Etage
91300 Massy, France
Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79

Germany
Microchip Technology GmbH
Steinheilstrasse 10
D-85737 Ismaning, Germany
Tel: 49-89-627-144-0
Fax: 49-89-627-144-44

Italy
Microchip Technology SRL
Via Quasimodo, 12
20025 Legnano (MI)
Milan, Italy
Tel: 39-0331-742611 Fax: 39-0331-466781

United Kingdom
Microchip Ltd.
505 Eskdale Road
Winnersh Triangle
Wokingham
Berkshire, England RG41 5TU
Tel: 44-118-921-5869 Fax: 44-118-921-5820

05/30/03

© 2003 Microchip Technology Inc.

This datasheet has been downloaded from:

www.EEworld.com.cn

Free Download

Daily Updated Database

100% Free Datasheet Search Site

100% Free IC Replacement Search Site

Convenient Electronic Dictionary

Fast Search System

www.EEworld.com.cn

All Datasheets Cannot Be Modified Without Permission

Copyright © Each Manufacturing Company